MATHEMATICAL ELEMENTS OF Natural Philosophy, Confirm'd by EXPERIMENTS: OR, AN INTRODUCTION TO Sir ISAAC NEWTON's Philosophy.

VOL. II.

Written in LATIN

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Translated into ENGLISH

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BRITISH MUSEUM

TO THE

Most Noble and Right Honourable

THOMAS

Lord *PARKER*,

BARON of *Macclesfield*,

Lord HIGH-CHANCELLOR of *GREAT BRITAIN*, &c.

My LORD,

IF whilst your Lordship's Hours are taken up with an Employment of the greatest Fatigue as well as the highest Honour, there can be any Time allow'd for Recreation, your Lordship makes that your Diversion, which few can attain to

without painful Application and laborious Study. To become a skilful Mathematician and a ſound Philoſopher, and at the ſame time ſhine in other Parts of Learning, requires a great and extenſive Genius; but to lead a Life of Buſineſs, and be eminent in the Law, where Reputation is only got by conſtant Practice, as well as Brightneſs of Parts; and yet in thoſe few Minutes of Leiſure that are allow'd to breathe in, and are as it were ſtolen from Sleep, to play with all the Intricacies of Lines and Numbers, to view and underſtand the Syſtem of the World, the Proportion, Symmetry, and Harmony of its ſeveral Parts; to be acquainted with all the Experiments of Conſequence that have been made, and be able to contrive new ones as uſeful as inſtructive, was only reſerv'd to Men of uncommon Capacities, and to none in ſo eminent a Degree as to your Lordſhip.

 THE

DEDICATION.

The Honour I have had of being admitted into your Lordſhip's Converſation, has given me an Opportunity to know which of the Mathematical Sciences are chiefly lik'd by you; and as Astronomy and Optics ſeem to have the Preference, I thought this Tranſlation of Dr. *'s GRAVESANDE*'s Second VOLUME would not be unacceptable.

Here you have the Principles of the common Optics reduc'd into a ſmall Compaſs, and confirm'd by new Experiments of the Author's own Invention; a fine Application of the Action of electric Bodies to diſcover the Nature of Fire; and Sir *ISAAC NEWTON*'s Doctrine of Light and Colours prov'd by the moſt conſiderable of his

Experiments, which Dr. *'s Graveſande* performs with an Apparatus very ingeniouſly contriv'd, and nicely expreſs'd by curious Figures. The laſt Part of this Volume not only leads a Beginner gradually on from the moſt ſimple to underſtand the moſt difficult *Phænomena* of ASTRONOMY, but gives ſuch a phyſical Account of the celeſtial Motions as muſt be fully ſatisfactory to the beſt Geometricians; there your Lordſhip will ſee with Pleaſure, that there are Profeſſors abroad who underſtand the *PRINCIPIA*, and have ſo juſt a Value for that excellent Book, as to take Pains to propagate the wonderful Truths which it demonſtrates, ſo as to make them plain to ſuch Philoſophers as are not yet able to go thro' all the difficult Propoſitions from whence they are deduc'd. But I will detain your Lord-

ſhip no longer, either from the important Buſineſs of your Station, or the pleaſing Truths of the AUTHOR, than while I beg leave to ſubſcribe myſelf,

My LORD,

Your Lordſhip's

moſt obliged,

moſt obedient, and

moſt humble Servant,

J. T. DESAGULIERS.

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The AUTHOR's PREFACE.

I *Spoke of the Method of Reasoning to be used in natural Philosophy in the first Chapter of the first Volume, and in the Preface endeavour'd to vindicate the Goodness of the Method I have followed. There are several remarkable Specimens of this Method in the present Volume, which evidently shew Sir* Isaac Newton*'s great Superiority of Genius above all other Philosophers.*

Before him Naturalists were in the Dark in numberless Things relating to Light, and especially to Colours. For Instance, who ever suspected before that the Opacity of Bodies depended upon their Interstices? So that a Body becomes transparent when these Interstices are filled with a Medium of the same Density as the Particles of the Body itself.

His

His Account of the planetary System, and particularly of the Motion of the Moon, is not less worthy of eternal Praises, being likely to carry Astronomy to a greater Pitch of Perfection than the nicest Observations alone could possibly do; for if a Man is acquainted with the Laws that govern the System of the World, he will be able to make a better Use of his Observations, and to compute the Motions of the heavenly Bodies more exactly, than if he had nothing but Observations to direct him.

It was my Design in these Two Books to give my Reader a general Notion of the chief Things discover'd by Sir Isaac Newton *in natural Philosophy, and thereby to encourage him to the Study of the more abstruse, and at the same time more sublime, Parts of Mathematics, after he has learned the first Principles of Geometry, to fit him for the reading of these plain Elements; he will, as it were, go to the Fountain-Head when he reads the Writings of our great Philosopher, which will reveal such Things to him as were unknown to the profoundest Philosophers before him; and which, tho' publish'd, are still a Secret to all but thorough Mathematicians.*

I have only a few Words more to say to the English *Reader concerning the two* English *Translations of this Work.*

As tedious and distasteful as an Author's Complaints generally prove, they cannot however be disallow'd, when they are grounded upon such an Injury done to the Author, as it is his Reader's Interest to be inform'd of.

Soon after the Publication of the first Volume of these Elements, *it was translated into* English, *and printed in* London, *with the Name of a celebrated Professor of Mathematics, eminent for his Writings, inscrib'd on the Title-Page, as if he had look'd over and corrected this Translation;*

Translation; but whoever examines any one Page in the Book, will immediately discover the Wrong done to that learned Gentleman, and the Abuse made of his Name, since he will every where perceive manifest Signs of the Translator's Ignorance of the very Principles of Physics and Mathematics, not to mention his Negligence with regard to the correcting of the Additions at the End of the Book, to the Numbers in the Margin, and the Distinction of the Propositions.

Dr. DESAGULIERS, *whose Knowledge of Philosophy and Skill in making Experiments are so well known, began to translate the same Work about the same Time as the other, or rather before; but this obliging him to make more than ordinary Haste, he could not himself wholly avoid the usual Consequences of too much Precipitation,* &c.

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Mathe-

Mathematical ELEMENTS
OF
Natural Philosophy,
Confirm'd by
EXPERIMENTS.

VOL. II. BOOK III.

PART I. *Concerning FIRE.*

CHAP. I.

Of the Properties of Fire in general.

THO' we know ſeveral Properties of Fire, yet we are ignorant of a great many things relating to it.

I ſhall not invent Hypotheſes, but reaſon from Experiments, and leave untouched what is not fully known.

Fire eaſily penetrates thro' all Bodies, however denſe and hard they are. For we have never yet known 544

any Body, that by the Application of Fire has not been heated in all its Points; that is, in every Part.

545 *Fire moves very swiftly*, as appears from Astronomical Observations.

546 *Fire unites itself to Bodies*; for when they are brought to the Fire, they grow hot, as we said
547 before; *and in that Case they expand or swell*: Which Expansion is also observed in such Bodies,
548 whose Parts do not cohere, in which Case *they also acquire a great Degree of Elasticity*, as is observed in Air and Vapours.

549 That *Fire is attracted by Bodies at a certain Distance from them*, will be shewn in the following
* 611 Part of this Book.*

If any Bodies are violently moved against one another, they will grow hot by such a Friction, and that to a great Degree; which shews that
550 *all Bodies contain Fire in them*: for, by rubbing, Fire may be put in Motion, and separated from Body, but can by no means be generated that way.

Having laid down these general Heads, we must examine several things more particularly.

CHAP. II.

That Fire adheres to Bodies, and is contain'd in them; where we shall also speak of Electricity.

As we have already said, one may prove that Fire is contain'd in all Bodies, because there are no Bodies but what may be heat-
* 550 ed by Attrition;* and that it coheres firmly with the Parts of Bodies, appears in Smoke and Vapours: for Smoke and Vapours are made up of Parts separated from Bodies, and agitated (sometimes

times very violently) by the Fire that is join'd with them.

There are, besides, several remarkable Phænomena arising from Fire, contained in Bodies, some of which we shall here mention; amongst which, there are such as relate very much to Electricity, for which Reason we must also treat of the Phænomena of Electricity.

Definition.

Electricity *is that Property of Bodies, by which* 551
(when they are heated by Attrition) they attract, and repel lighter Bodies at a sensible Distance.

Experiment 1.] Take two Pieces of Rock 552
Crystal and rub them together, and immediately they will appear luminous all over, tho' they do not acquire any sensible Heat by that Attrition. Light (as well as Heat) is a Proof that there is Fire in a Body. The greatest Light is in those Points, where the Bodies touch one another.

Experiment 2.] Take a Glass Tube 15 or 18 553
Inches long, and one Inch in Diameter, and rub it with a Linnen or Woollen Cloth, and it will emit Light in the Dark.

Experiment 3. *Plate* I. *Fig.* 1.] This Tube, 554
heated by rubbing, has a very sensible Electricity; for if light Bodies, such as Pieces of leaf Gold, and Soot, be laid upon a Plane, and the Tube be brought near them, they will be put in Motion, attracted, repelled, and driven several Ways by the Tube. The Tube acts at different Distances, according to the different State of the Air; sometimes at the Distance of one Foot; when the Air is full of Vapours the Effect is diminished.

555 There is one Thing remarkable, and very hard to explain in this Experiment, concerning the Direction of the Attrition; when you rub the Tube, one End of it is held in one Hand, whilſt it is rubb'd with the other; which, if it be done from the Hand that holds towards the other End of the Tube, the Effect will not be ſenſible; but if you rub from the free End of the Tube towards the End held in the Hand, the contrary will happen. And this happens indifferently, whether you hold the open or the ſhut End of the Tube in your Hand.

556 In the following Experiments (*Plate* I. *Fig.* 2.) glaſs Globes are ſwiftly whirl'd about; to perform which, there muſt be a cylindric Neck at each End of every Globe; but only one of theſe Necks is to be open, and both are to have Braſs Ferrels, ſuch as are repreſented at G; a Cock E muſt be ſcrew'd on to the Ferrel at the open Neck, and the oppoſite Braſs Ferrel muſt have a little Wheel *r* of about an Inch and a half Diameter, join'd to it, with a ſmall Braſs Axis ſtanding out: There is juſt ſuch another Piece of Braſs ſcrew'd on to the Cock, ſo that it may be taken on and off at pleaſure. Theſe Axes go about a Quarter of an Inch into the Pillars SS, that ſupport the Globe, and are Centers for it to whirl upon when it turns about its Axis.

The Pillars SS ſtand upon a ſtrong horizontal Board of about an Inch and a half thick, framed into three other Boards, as may be ſeen in the Figure: In that which ſtands foreright, there is an Hole *f* that you may come at the lower Part of the Pillar, to make it faſt with a Nut or Screw. The other Pillar S is likewiſe faſten'd by a Screw applied under the horizontal Board, and moved forwards and backwards in a Slit of 4 or 5 Inches long, before it be made faſt, in order to take the Glaſs

Glaſs Globes in and out, and to take in ſuch as are larger or ſmaller than others, according to the different Experiments to be made.

There is a great Wheel R which is turn'd round by means of the Handle M, and thereby gives a very ſwift whirling Motion to the Globe G.

In the Side of the upper Board, there is a Slit, along which the Pully *t* may be moved, by means of the Screw *c*, in order to keep ſtretch'd the Rope that goes round the Wheels R and *r*.

Experiment 4 & 5. *Plate* II. *Fig.* 1.] Apply a Glaſs Globe of about 8 or 9 Inches Diameter, to the Machine above-mention'd, and let it be briſkly whirl'd in a dark Place, the Hand all the while being held againſt it, to give it Attrition. 557

If the Globe be exhauſted of its Air, it will appear all luminous within, but moſtly ſo where the Hand touches the Glaſs.

But if the Globe has Air in it, and being whirl'd in the ſame manner, the Hand be applied to it, no Light appears, either in the inner or outer Surface of the Glaſs; but Bodies at a ſmall Diſtance from the Glaſs (as for Example, at a Quarter of an Inch, or nearer) become luminous; and ſo only thoſe Parts of the Hand held againſt the Glaſs, which terminate, or rather environ the Parts that immediately touch the Globe, are luminous. 558

Experiment 6. *Plate* I. *Fig.* 2.] Take the Globe made uſe of in the foregoing Experiments, and put it in between the Pillars, to whirl it as before: Then take a Braſs Wire *a b d*, circularly bent in the upper Part, and fix it ſo that its curve Part may be about 4 Inches off of the Globe, with ſmall Threads hanging from it, which being extended towards the Center of the Globe 559

come within a quarter of an Inch of the Surface of the Globe.

Whirl the Globe and apply the Hand, and immediately the Threads will be moved irregularly by the Agitation of the Air; but when the Glass is heated by the Attrition, all the Threads are directed towards the Center of the Globe, as may be seen in the Figure: And if the Hand be applied a little on one Side, or nearer the Pole of the Globe, the Threads will be directed towards that Point of the Axis which is under the Hand.

560 If the Air be drawn out of the Globe, this whole Effect ceases.

561 *Experiment* 7. *Plate* I. *Fig.* 3.] Take another Globe like the former; only differing in this, that the open'd Neck must have a larger Opening than that of the Globe G, so that you may put into it a round flat Piece of Wood *o*, that has a Brass Wire for its Axis. In order to fix this Piece of Wood in the Middle of the Globe, its Axis must be firmly screw'd to the Middle of the Cover that is join'd to the open Neck of the Globe at *b*: and the Cock E is also join'd to the Middle of the Cover on the Outside.

To the wooden Circle small Threads are fasten'd, which, being extended, almost touch the inner Surface of the Globe.

Turn the great Wheel so as to whirl the Globe, and rub it till it becomes warm, as was done in the former Experiments; if you cease to whirl the Globe, and the Hand be taken off, the Threads will immediately stretch themselves out like Radii from the Center towards the Surface of the Globe, yet they hardly remain one Moment at rest; for tho' the Globe be exactly shut, these Threads will be put in Motion, as appears

appears by blowing against the Globe, tho' you stand two Foot off, or farther, from the Globe. If you bring your Finger towards the Globe, tho' you do not touch it, the Threads next to it will be attracted by the Finger, and directed towards it; nay, and sometimes they fly from it. If you apply the whole Hand to the Globe, the Threads will be mov'd violently and irregularly.

And if all the Air be drawn out, as in the foregoing Experiment, the whole Effect ceases; and the Threads (both before and after the Friction) only hang down by their Gravity. 562

If we attend to all the foregoing Experiments, the following Conclusions seem to be naturally deduced from them, which we do not give out as certain, but very probable; for we must always distinguish Certainty from Probability.

That Glass contains in it, and has, about its Surface, a certain Atmosphere, which is excited by Friction, * *and put into a vibratory Motion*; for it attracts and repels light Bodies; * the smallest Parts of the Glass are agitated by the Attrition, and by reason of their Elasticity, their Motion is vibratory, which is communicated to the Atmosphere above-mention'd; and therefore that Atmosphere exerts its Action the farther, the greater Agitation the Parts of the Glass receive when a greater Attrition is given to the Glass. 563

* 554, 559, 561.

* 554

The Fire, contained in the Glass, is expell'd by the Action of this Atmosphere; at least it is mov'd with it. For when light Bodies are put in Motion at a Distance from the Glass the Bodies also become lucid at a Distance.* 564

* 559, 558.

It is plain, that *this Atmosphere and Fire is more easily mov'd in a Place void of Air*: For if the Globe be exhausted of its Air, there can be perceiv'd no Light, nor any Effect of Electricity on the Outside of the Globe,* but the Inside of the 565

* 557, 560.

Globe appears very luminous, and this Fire is
perceiv'd to be in greater Quantity in this Ex-
periment, than in that immediately after men-
* 558 tion'd.*

But the Action of the Electricity does alſo
* 562 ceaſe on the Inſide when the Air is drawn out,*
which ſeems to overthrow what we ſaid of the
more eaſy Motion of the Atmoſphere of Glaſs
in Vacuo: But yet it is not probable that it ſhou'd
move no whither in this Caſe. On the contrary,
it ſeems to go the ſame way as the Fire, and
to move that way where there is the leaſt Reſiſt-
ance; and that the ceaſing of the Action of E-
lectricity is to be attributed to the Want of Air,
566 by means of which, *the Threads are moved by the*
* 605 *Atmoſphere*; as we ſhall hereafter ſhew; * and the
* 607 Fire, which freely penetrates all Bodies, acts
upon them violently *by means of the Air* or Va-
pour.

But laying aſide Conjectures, tho' they have
a great many Experiments for their Foundation,
let us return to other Things relating to Fire; as
ſeveral Experiments are to be made *in Vacuo*, we
muſt deſcribe the following *Machine* contriv'd to
give Attrition to Bodies *in Vacuo*.

567 *Plate* II. *Fig.* 2.] Let M be the Air-Pump de-
* 437 ſcrib'd before,* L L the Braſs Plate of the Pump
on which the Glaſs Receivers are ſet; on each
Side of the Plate there is a wooden Pillar, A D,
A D, which Pillars ſtand on the Board that car-
ries the Air-Pump Plate, having their Baſe upon
it, and a Part below the Baſe, and going thro'
the Board with an Hole in it, to receive two croſs
Pieces of Wood or Wedges, that make them
faſt during the Experiment, but ſo that the ſaid
Pillars may be taken away afterwards.

The Glaſs Receiver, in which the Experiments
are to be made, is about 9 Inches high, and 6
in

in Diameter, with a Cover * that has annex'd to * 440
it a Box or Collar full of oil'd Leathers thro' which a Braſs Axis paſſes; and leſt in the whirling round of the Axis the lower End ſhou'd move, Part of the Box is made ſquare, ſo as exactly to fit a ſquare Hole in the Horizontal Board E E that preſſes on the Cover, and is made faſt by bringing down the Nuts or Screws BB at each End, without bearing upon the Shoulders of the Pillars.

Towards the upper Part of the Pillars, there is a narrower horizontal Board F F preſs'd down alſo and faſtened with Nuts, which has fix'd to it, on the under Side, a Piece of Braſs *g*, with an Hole in it for the upper End of the above-mentioned Axis to turn in, whilſt the biggeſt Part of this Axis, being in the middle of the Glaſs, has an outſide Screw upon it, with the two Wing-Nuts *d*, *d*, moveable upon it, in order to faſten ſeveral Bodies upon the Axis.

The lower End of the Axis turns in the Hole *c*. The Braſs Spring *ff* is joined to the Piece *c*, which ſcrews it down to the Air-Pump Plate at the Hole where the Air is drawn out; but there muſt always be made a ſmall Hole or Paſſage in the Piece *c*, for the Air to be drawn out at.

Having exhauſted the Receiver, the Axis above-mentioned (by reaſon of the oiled Leathers in the Collar P) may be turned round without admitting any Air; but to give it a quick Motion, there is a little Braſs Wheel *r* of about 2 Inches Diameter, with Points in its Groove, that the Rope, that turns it round, may not ſlip.

The great Wheel R, of about 3 Foot Diameter with its Frame, is brought up cloſe to the Air-Pump, and made faſt to its Foot by a Screw.

The Rope, that goes about the leſſer Wheel *r*, is brought down over Pullies obliquely placed

in

in the upper Part of the Pillars C, C, and being over them, comes down to the great Wheel which it goes round; ſo that by turning the vertical Wheel R, the Braſs Axis, above deſcribed, is carried round very ſwiftly, whereby a Motion is communicated to Bodies *in Vacuo* for ſeveral Experiments.

568 *Experiment* 8.] Take a Glaſs Globe of three Inches Diameter, or of two Inches and a half Diameter, with an Hole on each Side, where it may alſo have cylindric Necks. The Axis abovemention'd muſt go thro' thoſe Holes, in order to give the Globe a whirling Motion; Pieces of Cork muſt be put on each Side of the Globe to cover its Holes, and made faſt with the Nuts *d*, *d*, in the manner that they appear in the Figure, to hold faſt together the Plates or little Wheels, thro' which the Axis goes.

This Globe, thus fix'd, will be ſwiftly mov'd *in Vacuo* with its Axis, by turning the Wheel R: To cauſe Attrition, a Piece of Woollen Cloth muſt be tied on to each Side of the Braſs Spring *f*, *f*, which by its Elaſticity preſſes the Globe hard on each Side.

Making the Experiment in the Dark, the Globe will appear luminous; and if the Motion be continued till the Globe grows hot by the Attrition, the Light will indeed be increaſed, but will appear fix'd in the Places where the Attrition is made.

569 It follows from that Experiment, that *the Fire, contained in Glaſs, does not want Air to make it viſible*; for it grows hot, and ſhines when both the internal and external Air are taken out.

570 *Experiment* 9.] Take a round Piece of Wood of 2, or 2 ½ Inches Diameter, and about ½ an Inch

Inch thick, and let it have several Hollows cut in its Edge, that it may be encompass'd round with Beads of Plaister, which may be made fast to it with Threads going thro' them. Let this Piece of Wood, thus prepar'd, be made fast upon the Axis above-mention'd, in the same manner as the little Globe had been fasten'd; then give Attrition *in Vacuo*, as in that Experiment, and Light will be thereby produced in the Dark.

Experiment 10.] That Quicksilver contains Fire, 571
is plain from Experiments made upon it *in Vacuo*. For if Mercury well clean'd be shak'd about in an exhausted Glass, it will appear luminous.

If you put Mercury into a Glass Globe, the 572
Globe may be whirl'd round, as in the former Experiments, which will be delightful to see, if the Glass be mov'd slowly. If Mercury has no Tin mix'd with it, it may be clean'd with boiling hot Vinegar.

The Globe that has the Mercury in it, may be 573
exhausted by screwing on to it a Pipe about two Foot long, the lower End of which must be screw'd on to the Hole in the Middle of the Plate of the Air-Pump.

Then, if you cover both that Hole and the Hole thro' which the Air is drawn out with one of the Receivers above-mention'd, the Air will be easily drawn out of the Globe.

Plate I. *Fig.* 4.] Take a Plate O, and having 574
screw'd on to it the Pipe E E, whose other End is screw'd to the Air-Pump, put the Glass Receiver R upon it, and pump out the Air from it. The Pipe, through which the Air is drawn out, must stand up beyond the Plate in the Receiver about 4 or 5 Inches, be bent, and have a small Hole in it; which must be ta-

ken care of, for fear any Mercury shou'd get into the Air-Pump.

The middle of this Plate has a Brass Pipe B; whose lower End, that is without an Hole, comes down almost to the Bottom of the Vessel V, that contains very clean Mercury: There is an Hole in the Side of the Pipe, exactly shut by the Pin A. The upper End of this Pipe has a very small Hole in it, and comes up through the Plate into the Receiver.

The Height of the Receiver R is about 16 Inches, and its Diameter 4 Inches; pump the Air out of it, and then open the Hole in the Side of the Pipe B, and the Mercury by the Pressure of the external Air will go up to the Tube. and will spout very strongly into the Receiver, striking against the Top of it.

The Experiment must be made in a dark Place, and the Mercury will appear luminous.

575 *Experiment* 11.] Chymists make a certain Preparation of Urine, which they call *Phosphorus of Urine*; which must be kept in Water. If it be roll'd up into small cylindrical Pieces like a Pencil, and you write with it upon a Paper, when you hold the Paper in a dark Place, you will see Letters of Fire. The *Phosphorus* itself, when you take it out of the Water, will grow hot and smoke; all which shews that the *Phosphorus* contains a great deal of Fire.

576 In this Experiment, *we may observe that Water acts upon the Fire contain'd in the* Phosphorus; *for it keeps it in*, so that it cannot get out so long as the Phosphorus is cover'd with Water; but as soon as the Water is taken away, the Heat and Smoke immediately shew that the Fire issues

577 out of the Phosphorus. *The Air* also *does*, *in some measure, keep in the Fire contain'd in hot Water*;

that

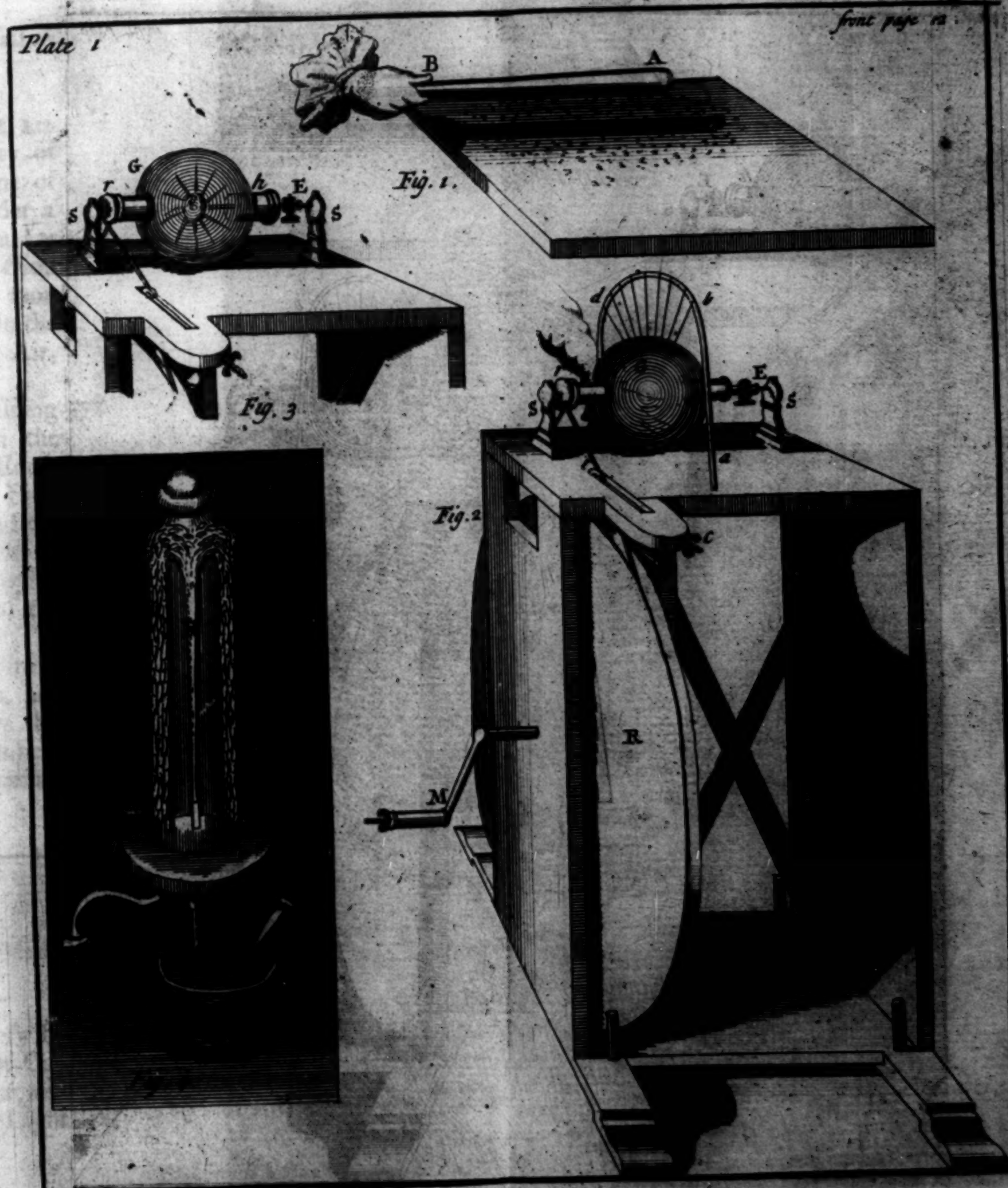

Plate 1
front page 12
Fig. 1.
A
B
Fig. 2
Fig. 3
G
h
E
S
M
R

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that is, hinders it from going out of it so fast as it will do *in Vacuo*.

Experiment 12.] Take two Vessels that are equal and alike, and put an equal Quantity of boiling Water into each of them. Let one of them be set upon the Air-Pump Plate under a Receiver, and pump out the Air; when you are pumping, the Water boils violently by the Action of the Fire that goes out of it; and then soon becomes only lukewarm, whilst the Water in the other Vessel, which remain'd in the open Air, has scarce lost any of its Heat.

One may observe something like this in shining 578
Wood; for some Wood that is rotted in the Ground, shines when it is taken out; the Earth that encompass'd the Wood kept in the Fire, which goes out when that is remov'd, and the Wood continues to shine for some Days. In an exhausted Receiver, the Light is soon destroy'd, and is not restor'd by the Re-admission of the Air.

But it cannot be easily determin'd how Fire is confined in a Body by the ambient Bodies, nor is it easy to find out what Action produces this Effect; it is hardly probable that Pressure is here much concerned, since Fire does easily penetrate all Bodies by its Subtilty.

CHAP. III.

Concerning the Motion of Fire, where we shall speak of Heat and Light.

WE have said that Fire moves very swiftly,* and this Motion, in different Cir- * 545
cumstances, produces different Effects. Heat and Light

Light are to be attributed to the different Moti-
579 ons of Fire. *Heat, in a hot Body, is the Agitation of the Parts of the Body and the Fire contained in it*; by which Agitation, a Motion is produced in our Bodies, which excites the Idea of Heat in
580 our Mind. *Heat, in respect of us, is nothing but that Idea, and in the hot Body is nothing but Motion.* Here we must call to mind what has been said of the Sensations in general (N. 502.) which also may be referr'd to Light.

581 *When Fire enters our Eyes in right Lines, by the Motion that it communicates to the* Fibres *in the bottom of the Eye, it excites the Idea of Light*; of which Motion of the Fibres we shall speak more
* 716 particularly hereafter.* *A rectilinear Motion* is
582 the Motion of Light, as it appears from its being easily stopped by an Obstacle. On the contrary, such Motion *is not requir'd in Heat*: and that *an irregular Motion is more for it*, may be proved, because the Rays, that come directly from the Sun to the Top of a Mountain, produce no sensible Heat; whilst in the Valley, where the Rays are agitated with an irregular Motion by several Reflections, there is often produced a very intense Heat.

Definition.

A Body *is said to be* Lucid, *when it emits Light*, that is, when it gives Fire a Motion in right Lines.

583 That *there is not always Light, where there is Fire*, is beyond all doubt; for we daily see hot Bodies that do not shine.

584 But *whether there be any Body without Heat, cannot be determin'd.* Heat, in all Bodies, is a Motion that may be infinitely diminish'd; and there may be such a Motion, tho' it be not sensible to us, because often we cannot discover

any

any thing of Heat; for certainly there are a great many lucid Bodies, in which we can perceive no sensible Heat.* Concerning which it * 571 may be observ'd, that no Heat is sensible to us, unless the Body, that acts upon our Organs of Sense, has a greater Degree of Heat than that of our Organs. Which shews us, that the Judgment of our Senses, concerning Heat, is wholly uncertain.

When the smallest Parts of which any Body is made up are agitated, either by Attrition, or the Action of Fire applied externally to it, or any other Way; the Fire is separated from the small Particles, and agitated in the Body; then also the Fire and the Particles of the Body act upon one another by their Attraction, as is prov'd by the Experiments which we shall hereafter mention.* By this Action some Parts are * 611 separated from the Body, and carried off from it by the Motion of the Fire. And this is the Cause why *hard Bodies are often set on Fire by a* 585 *violent Attrition.*

Hence we deduce, that *the burning of Bodies is* 586 *a Separation of their Parts by the mutual Action of the Fire and those Parts on each other*; some of *those Parts, carried off by the Motion of the Fire,* 587 *make Flame and Smoke.*

We see besides, that a Body, that is burned by the Application of Fire, is not only dissolv'd by the Action of the external Fire, but also by the Action of the Fire contained in the Body itself; and that the Heat is increased by the Application of new Fire, and the Augmentation of the Agitation of the Fire which the Body itself contains; and therefore that *the Heat is not in* 588 *proportion to the Quantity of Fire.*

As to the Motion of Light, it is plain, as we said,* that it is perform'd in right Lines; but * 581 whether

whether it be ſucceſſive or inſtantaneous, is diſputed; that is, whether at the ſame Moment that a Body begins to ſhine, the Light is ſenſible at any Diſtance, or whether the Light goes on ſucceſſively to Places more and more diſtant.

589 It ſeems clearly to follow from ſeveral Aſtronomical Obſervations, that that Motion is ſucceſſive, and Philoſophers did not long doubt of it; but by ſome later Obſervations, the Concluſions, drawn from the former, are weaken'd, and we are obliged to confeſs that the Motion of Light has ſomething unknown to us.

To ſay that a Motion from one Place to another is not ſucceſſive, implies a Contradiction, and *it can ſcarce be doubted, that Light moves from*
590 *one Place to another.*

For we obſerve that Fire is carried off in Vapours and Smoke; in which Caſe, Fire carries with it the Bodies to which it adheres, and yet is often mov'd very ſwift: If the Subtilty of Fire be conſider'd, it will eaſily be found that it is immenſly retarded by the Bodies to which it adheres; and, that, as ſoon as it is freed from them, it is mov'd with a very great Velocity.

There are ſeveral other Things very well worth obſerving, in reſpect to Light and Heat, but a great many of them are hard to explain. In natural Philoſophy, when we are ignorant of the Cauſes, we muſt only mention the Effects.

591 We ſee *ſeveral heated Bodies* that *become lucid, if their Heat be increaſed*; ſuch are Metals: They emit Fire by the Agitation of their Parts, but if the Motion of the Parts be increaſed, Part of the Fire is mov'd in right Lines, and the Body ſhines.

Thus

Thus if Smoke be made hotter by applying Flame to it, it is chang'd into Flame; that is, it becomes a lucid Body. 592

Experiment 1. *Plate* II. *Fig.* 3.] Having blown out the Candle C, which sends out the Smoke F; let another lighted Candle be brought to it, and the Smoke of the first will be chang'd into Flame, and that successively quite to the Candle C, which is thus lighted by the Candle A, tho' it be 7 or 8 Inches from it.

We have said that Air acts upon Fire *; one * 577
of its Effects upon it, that in many Cases is not to be overlook'd, shews itself in respect of Light. For *the Presence of the Air is often necessary for the* 593
Production of Light or Preservation of Fire, which may be observ'd in the burning of all those Bodies that go out when the Air is taken away from them.

Experiment 2.] Put a lighted Candle under the Receiver of the Air-Pump; exhaust the Receiver, and the Candle will immediately go out.

Plate II. *Fig.* 2. *Experiment* 3.] Take a round Plate of Steel of about 3 Inches Diameter, with an Hole in the Middle to receive the Axis which is to be mov'd *in Vacuo**, and let it be press'd * 567
and fix'd between two round Pieces of Wood by the Help of the Screws *d*, *d*; let Pieces of Flint be fasten'd to the Spring *f*, *f*, so that by the Motion of the Axis the Steel Plate may rub nimbly against the Flints. As long as there is any Air in the Receiver the Attrition will produce Sparks of Fire; when the Air is drawn out, tho you continue the Attrition you can perceive no Light; but upon re-admitting the Air, it becomes again sensible.

594 We observe also on the contrary, that *very often the Absence of Air is necessary for Light*, as might be observ'd in the Experiments already
* 557 mention'd*. *And* lastly, That *taking away the*
571 *Air, the same Light, which may be seen in the open*
595 *Air*, is sometimes *increased.*

* 575 *Experiment* 4.] With the *Phosphorus* * abovemention'd write or draw Figures upon Paper, and they will shine in the dark, as we said before; but the Paper will become much brighter *in Vacuo.*

CHAP. IV.

Of the Dilatation occasion'd by Heat.

596 ALL Bodies are dilated by the Action of
* 547 Fire*; but *that Dilatation* changes as the Heat changes; so that it *seems to depend rather upon the Motion than the Quantity of the Fire*; for Bodies are expanded as well by rubbing as by applying Fire to them externally.

Experiment 1. *Plate* III. *Fig.* 1.] Take a square Iron Bar about 3 Foot long and ¼ of an Inch thick, and having laid it upon the Board between two firm Obstacles or Standards O, O, between one of the Obstacles and one End of the Bar, thrust in an Iron Ruler about 4 or 5 Inches long (made Wedge-Fashion, being ½ of an Inch broader at R than at *r*, and divided into equal Parts) as far as it will go; and observe the Division, that is against the End of the Bar, which must be a little oblique, that it may the better appy it self to the Ruler.

Then let the Bar be heated, either by Attrition or Fire; then let it again be put between

 the

the Standards, and the Ruler thrust in between: As the Ruler will not go in so far as the Division that was observ'd before, it is plain that the Bar is lengthen'd by Heat.

Experiment 2. *Plate* II. *Fig.* 4.] That *Liquids, as well as Solids, are dilated by Heat* may be prov'd 597
in the following Manner. Take a Glass Ball G that has a small Tube E D for its Neck, and fill it with some Liquor up to what Height you please in the Tube, and the Liquor will ascend in the Tube, when you heat the Ball; a small Degree of Heat will produce this Effect, even tho you use Mercury, the densest of all Fluids. The Experiment will be made in the same Manner, but better, if instead of a Ball you use an hollow Cylinder C with the long Tube B A join'd to it; for the whole Liquor will be sooner heated in a Cylinder than in a Ball.

If the Tube E D or B A be divided into equal Parts; or the Tube with its Ball or Cylinder be fitted to a Frame on which equal Divisions are mark'd, the Heat may in some Sort be measured by this Machine: For the Liquor rises or subsides in the Tube, as the Heat of the neighbouring Bodies is increas'd or diminish'd. Such Instruments are call'd *Thermometers*, and are of 598
common Use. They do indeed shew a Change 599
in the Heat, but it is uncertain whether they shew the Degree of Heat; that is, it is not known what Relation there is between the Change of Expansion and the Change of Heat, so as to enable us to compare together the Degrees of Heat, by comparing the Degrees of Dilatation.

If the Ball G or Cylinder C be suddenly heated, 600
the Liquor in the Tube will immediately descend, but immediately after rise. By reason of the sud-

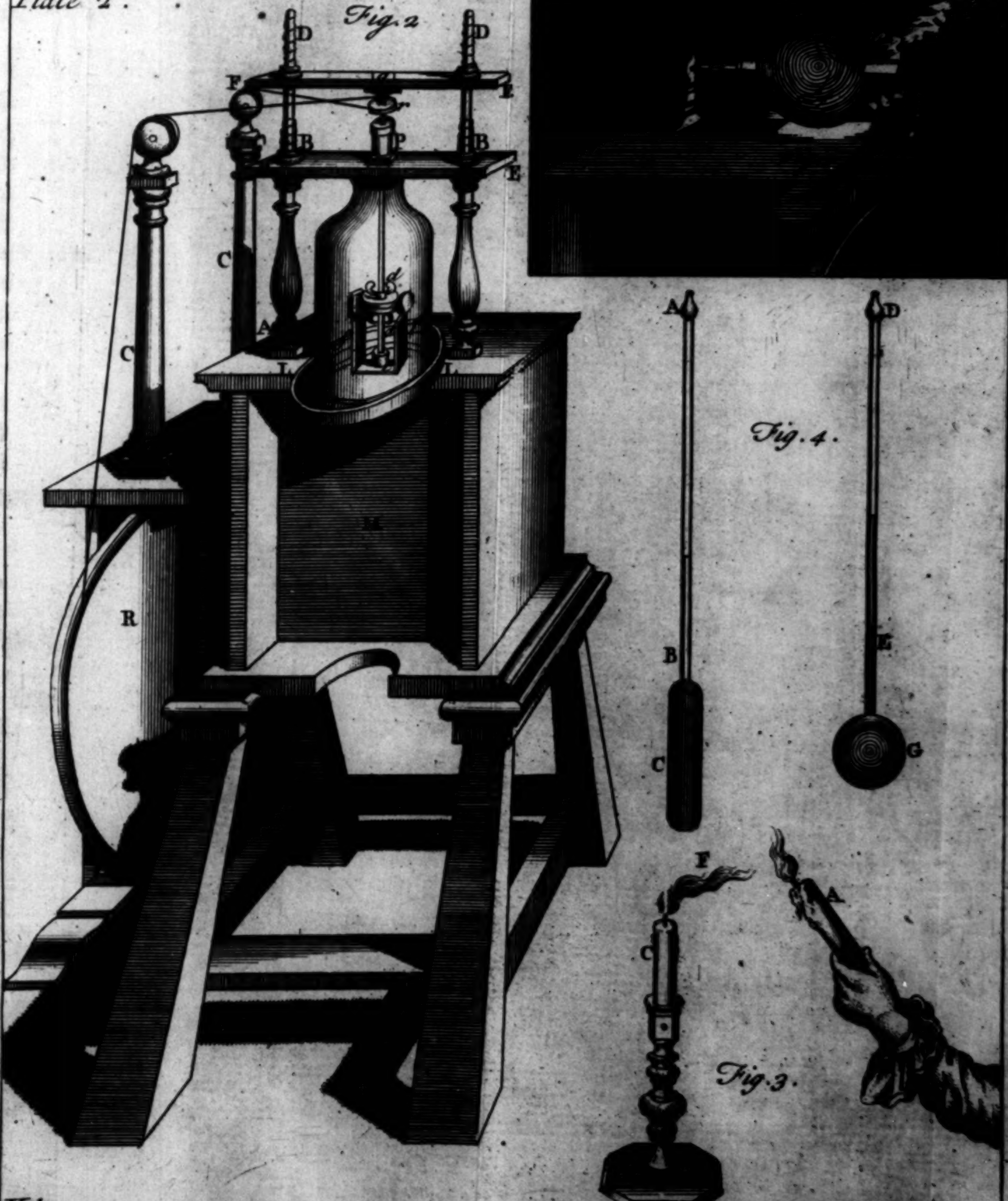
 den

den Heat the Glaſs it ſelf grows hot ſooner than the Liquor contain'd in it; and therefore when the Glaſs is dilated by the Heat, the Cavity grows bigger, ſo that the Liquor deſcends; but the Heat being preſently communicated to it, it riſes again by its Expanſion.

From the Expanſion of Bodies it is evident
601 that *the Particles of which Bodies conſiſt, from the Action of the Fire, acquire a repellent Force, by which they endeavour to fly from each other*, and which acts contrary to that Force by which the Parti-
* 31 cles come to each other *. As long as this laſt Force is ſtronger than the other, the Particles, cohere more or leſs, according to the different Degree of Heat. When the repellent Force is almoſt equal to the attractive, the Particles, which were before firmly join'd, ſcarcely cohere, yield to any Impreſſion, and are eaſily mov'd one among another; whence we ſee that *a So-*
602 *lid Body is changed into a Liquid by Heat*, which may be obſerv'd in all Bodies that are liquified by Heat, and return to their firſt State upon the Diminution of the Heat. It is a Queſtion,
603 *Whether all Fluidity is not owing to Heat?* which *cannot be determin'd*, becauſe we know of no Body that is entirely without Fire in it; it is certain that Heat is not only the Cauſe of Fluidity in Metals, Wax, and ſuch like Bodies, but that ſeveral Bodies, which are commonly reckon'd Fluid, are only ſo by reaſon of their Heat; thus
604 *Water is melted Ice*; for when Part of the Heat of the Water is gone, it grows fix'd.

605 Heat may be ſo increas'd that in ſome Bodies the attracting Force is overcome by the repelling Force; in which Caſe the Particles fly from each other; that is, acquire an elaſtic
* 431 Force, as the Particles of Air have*, which Elaſticity is increaſed even in the Air by Heat.

Plate 2.



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We may obſerve this Effect in Smoke and Vapours.

Experiment 3. *Plate* III. *Fig.* 2.] Take an hollow Braſs Ball E, of about 4 Inches Diameter, with an Handle M; This Ball has a Pipe T with an Hole of hardly the twentieth Part of an Inch. Let this Ball be heated, and the Air in it will expand itſelf * and come out thro' the Pipe; * 597
then, immerging the Ball in cold Water, the Air will be again condens'd by the Cold, and the Water will go into the Ball, by the Preſſure of the Atmoſphere upon its Surface.

If this Ball, thus partly filled with Water, be laid upon the Fire, the Moment that the Water is chang'd into Vapours, thoſe Vapours will go out thro' T; but if the Heat be increas'd, ſo as to make the Water boil violently, the Vapours, compreſs'd in the upper Part of the Ball, will by their Elaſticity, endeavour to recede from each other every Way, and ruſh violently out of the Pipe. Such an Inſtrument is call'd *Æolipile*. 606

Experiment 4.] The following Experiment 607
ſhews a more ſenſible Effect of the Elaſticity of Vapours.

Plate III. *Fig.* 3.] Take the Ball E, which is alſo of 4 Inches Diameter, made of Braſs or Copper, but thicker than the former, and let it be placed upon a little light Cart, ſuch as is repreſented in the Figure. In its upper Part, it has a ſquare Pipe T. In the middle of this Pipe, there is a Separation, and the hind Part of the Pipe communicates with the Ball. There is an Hole of about $\frac{1}{7}$ of an Inch, in the middle of the Separation of the Pipe, which Pipe is open forwards. This Hole is ſhut up with a long Plate, that goes thro' two Holes in the

Sides of the Pipe, and applies itself to the abovemention'd Separation. As the Plate is made Wedge-wise, if you strike upon it with a Hammer, it will exactly shut the Hole.

Take this Ball off the Cart, and open the Hole, and, having heated the Ball, immerge it in Water, to let it be in Part fill'd, as in the last Experiment. Then, having shut the Hole, set the Ball again upon the Fire, till the Water boils violently; and then if you make it fast to the Cart, and open the Hole, the Vapour will fly out violently one Way, and the Cart be carried with the Ball the contrary Way.

608 The Vapour, being very strongly compress'd, endeavours to recede equally every Way, and therefore opposite Pressures destroy one another; but when the Hole is open'd, the Vapour, which goes out, does not press; therefore the Pressure one Way being taken off, that which acts in a contrary Direction prevails, and the Cart is mov'd along.

609 A Sky-Rocket rises up into the Air, because the Gun-powder, being set on Fire, acquires an Elasticity, and its Parts endeavour to recede every Way: As the Pipe, or Case of it, is open at one End, it is less press'd that Way, and consequently at the other End, the Pressure prevails, and carries up the Rocket.

BOOK III.

PART II.

Concerning the Inflexion, Refraction and Reflexion of Light.

CHAP. V.

Concerning the Inflexion of the Rays of Light.

HAVING premis'd, in the foregoing Part, what regards Fire in general; let us again farther examine the Properties of Light and the Phænomena arising from them.

The Things observ'd concerning Light are very wonderful, yet most of them are explain'd by a few Laws of Nature.

Light moves in right Lines*, can be inter- * 581
cepted by an Obstacle which wholly stops so much Light as comes upon it, but stops no more.

DEFINITION.

Any Light consider'd according to the Direction 610
of its Motion, if it be all carried in the same Direction, is call'd, a Ray of Light.

Such is a Beam of the Sun's Light going thro' an Hole.

Fire, as has been ſaid, is attracted by Bo-
* 549 dies *; the notable Effects of which Attraction may be obſerved in the burning of Bodies; they
611 are alſo ſenſible in Light; for *when Light paſſes near Bodies, it is turn'd out of the ſtrait Way*; which may be diſtinctly perceiv'd by the following Experiment.

Experiment 1. *Plate* III. *Fig.* 4.] Take a little Board T about 6 Inches long, and as high, with an Hollow *c c* in its Surface, in which two Plates of Steel ſlide, each of which has an Edge like a Knife; the two Edges may be brought together in the middle of the Board, and be join'd together exactly. At the Place where they meet, there is a ſquare Hole in the Board, of almoſt an Inch, that a Beam of Light, let into a dark Room thro' an Hole of a Quarter of an Inch in Diameter, may paſs thro' the ſaid ſquare Hole, ſo as to come to the Plates.

If the Diſtance between the ſaid Edges be of about the 10th Part of an Inch, and the Light be made to paſs between them, the Board being ſet at the Diſtance of 3 Foot from the Window, if the Light falls upon the Paper A, at 5 Foot beyond the Board, there will appear, on each Side of the tranſmitted Beam, a Light like that of the Tail of a Comet; which proves that the *Light is inflected* as it paſſes by the Edges of the Plates, as is plain from the Figure.

If you bring the Plates nearer (as for Example) within the hundreth Part of an Inch, inſtead of the Light above-mention'd, you will, on each Side of the Light of the Beam upon the Paper, ſee three colour'd Fringes, parallel to the

Edges of the Plates; which will ſtill appear more diſtinct, if the Hole in the Window be made leſs. I ſhall hearafter explain whence theſe Colours ariſe. Now it is enough to deduce from this Experiment, that Light *is attracted* by Bodies that inflect its Rays; for if there was not a Motion towards the Body, the whole Beam would have continu'd in its direct Motion.

But *the Action of Bodies, by which they act upon the Light to attract it, exerts itſelf at a ſenſible Diſtance*; as is plain from the Experiment. 612

Experiment 2. *Plate* III. *Fig.* 4.] Every thing elſe being as in the former Experiment, if the Plates be brought nearer together within $\frac{1}{400}$ Part of an Inch, no Light will appear upon the Paper between the Fringes above-mention'd; ſo that in this Caſe, all the Light, which paſſes between the Edges, is inflected on either Side, ſo as to produce the Fringes above-mention'd. Which plainly ſhews, that Steel acts upon Light at leaſt at the Diſtance of $\frac{1}{800}$ Part of an Inch.

It is alſo proved, that *That Action is increas'd as the Diſtance is diminiſh'd.* 613

Experiment 3. *Plate* III. *Fig.* 4.] Things being ſtill in the ſame Diſpoſition, leſſen the Diſtance between the Plates; and the Fringes will vaniſh ſucceſſively, till the Plates being join'd together, no Light paſſes between them. The Fringes, which vaniſh firſt, are thoſe that are produced by the Rays which are leaſt inflected; and thoſe vaniſh laſt which are produced by the Rays that are moſt inflected; that is, when the Edges come towards one another, the Shadow between the Fringes, made by each Edge, is continually increas'd, till, at laſt, the whole Light on each Side vaniſhes. Whence it plainly follows, that the

the Rays are more inflected, the nearer they pass by the Edges; that is, the Attraction is increased, as the Distance is diminish'd.

614 But this Attraction has something particular, for *the Attraction of one Edge is increased, as the other is brought near it.* Which is plainly seen in this Experiment; for as the Edges are brought towards one another, the Inflection of the Rays continually becomes greater.

CHAP. VI.

Concerning the Refraction of Light and its Laws.

615 A*LL that gives Passage to Light, is call'd a* Medium.

Glass, Water, and a Vacuum itself are Mediums.

When a Ray of Light goes out of one Medium into another, it is often turn'd out of the right Line.

DEFINITION II.

This Inflection is call'd *Refraction.*

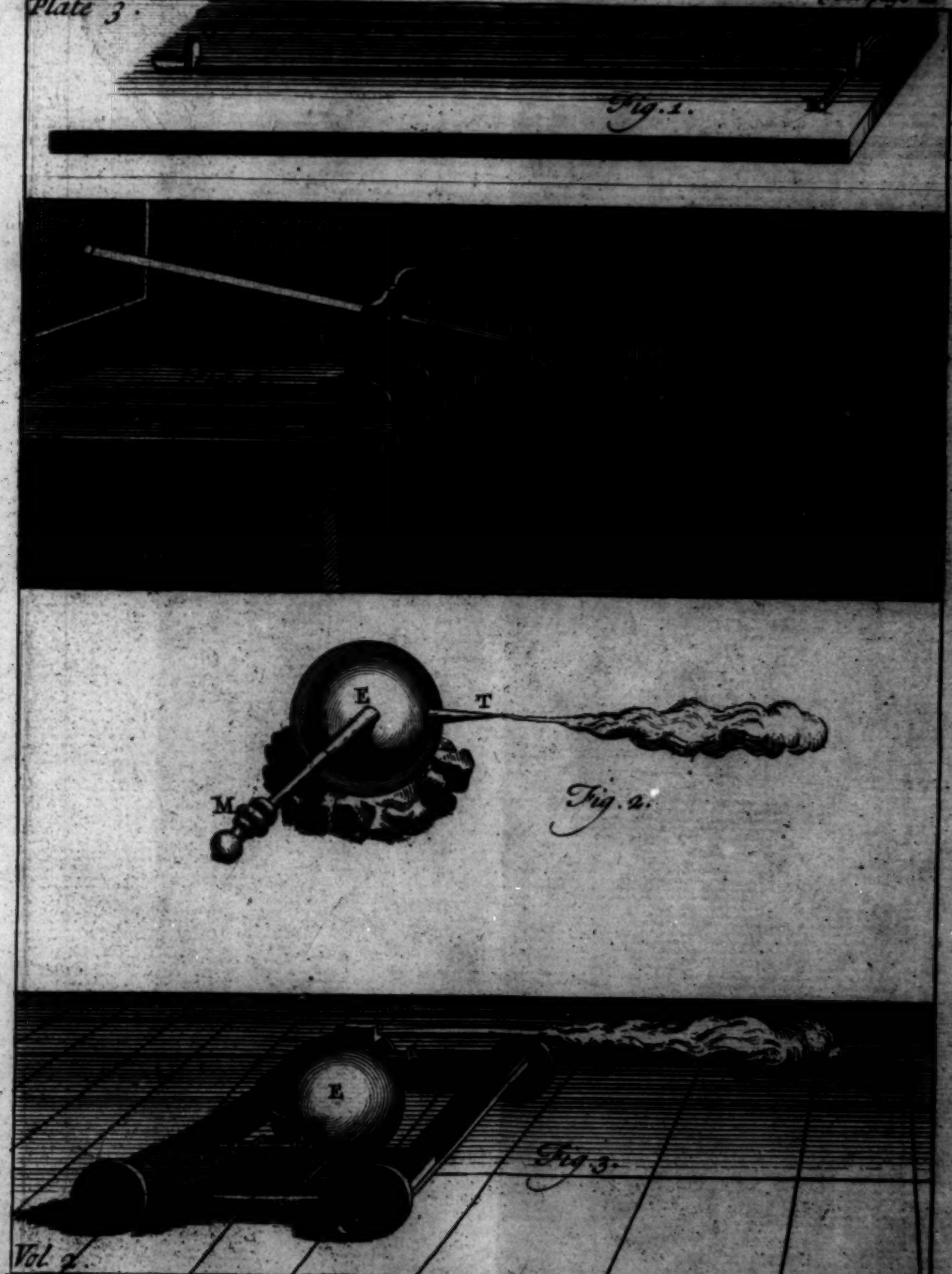
616 *In order to produce Refraction, the Mediums must be of different Densities, and the Ray must make an oblique Angle with the Surface that separates the Mediums.*

618 *Refraction arises from this, that the Rays are more attracted by a dense, than by a rare Medium;* from which Attraction, that we have prov'd in the foregoing Chapter, all that relates to Refraction may be deduced.

619 Let EF be the Separation of the Mediums [*Plate* IV. *Fig.* 1.] and let X be in the denser, and Z in the rarer Medium. All the Particles have
* 31 an attractive Force *, and this Force also obtains
* 611 in Light. Let the Distance, at * which the Particles exert their Action, be that which is comprehended between the Lines EF and GH.

2 Therefore,

Plate 3. front. page [illegible]



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Therefore, the Light, which comes between those Lines, will be attracted by the Medium X.

At the Distance of the Line G H, only the extreme Parts of the Medium X act upon the Light; at a less Distance, both they and other Parts act so as to increase the attracting Force, when the Distance is diminish'd, as has been before observed*. In the denser Medium X, let the Line * 613 I L be supposed at the same Distance from E F as G H is in the Medium Z. Let the Light enter into the Medium X, and it will, on all Sides, be attracted by the Particles of the Medium, whose Distances from the Light are less than the Distance between E F and G H; for the Light is suppos'd to be attracted at that Distance by the Particles of the Medium X.

As long as the Light is between the Lines E F and I L, the attracting Force is the strongest towards I L, because there are more Particles that draw that Way; but as the Number of Particles, that act the contrary Way, increases, that is, as the Distance from E F increases, the Force towards I L is diminish'd, till, in the very Line I L the Light be equally attracted every Way; which also obtains every where in the Medium X, beyond I L.

Suppose a Ray of Light to come in the Line A *a*, and fall obliquely on the Surface, which divides the Mediums, or rather on the Surface G H, where the Action begins, by which the Light is driven towards the Medium X: When the Ray comes to *a*, it is turn'd out of the right Line, by the Force by which it is attracted by the Medium X; that is, by which it is driven towards it in a Direction perpendicular to its Surface. And, indeed, the Ray of Light is bent out of the right Line in every Point, as long as it is between the Lines G H and I L, between which

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Therefore, the Light, which comes between those Lines, will be attracted by the Medium X.

At the Distance of the Line G H, only the extreme Parts of the Medium X act upon the Light; at a less Distance, both they and other Parts act so as to increase the attracting Force, when the Distance is diminish'd, as has been before observed*. In the denser Medium X, let the Line I L be supposed at the same Distance from E F as G H is in the Medium Z. Let the Light enter into the Medium X, and it will, on all Sides, be attracted by the Particles of the Medium, whose Distances from the Light are less than the Distance between E F and G H; for the Light is suppos'd to be attracted at that Distance by the Particles of the Medium X.

* 613

As long as the Light is between the Lines E F and I L, the attracting Force is the strongest towards I L, because there are more Particles that draw that Way; but as the Number of Particles, that act the contrary Way, increases, that is, as the Distance from E F increases, the Force towards I L is diminish'd, till, in the very Line I L the Light be equally attracted every Way; which also obtains every where in the Medium X, beyond I L.

Suppose a Ray of Light to come in the Line A *a*, and fall obliquely on the Surface, which divides the Mediums, or rather on the Surface G H, where the Action begins, by which the Light is driven towards the Medium X: When the Ray comes to *a*, it is turn'd out of the right Line, by the Force by which it is attracted by the Medium X; that is, by which it is driven towards it in a Direction perpendicular to its Surface. And, indeed, the Ray of Light is bent out of the right Line in every Point, as long as it is between the Lines G H and I L, between

which the ſaid Attraction acts; and therefore between thoſe Lines it deſcribes the Curve *a b*,
* 208 in the ſame Manner that Projectiles move*. Beyond the Line I L, the Action which bends the Ray ceaſes; therefore it goes on then in a right Line, according to the Direction of the Curve in the Point *b*.

The Diſtance, between the Line G H and I L, is very ſmall; therefore, when we conſider Refraction, we take no notice of the bended Part of the Ray, which we look upon as if it was made up of two ſtrait Lines A C, C B, meeting at C, namely, on the Surface which divides the Mediums.

Thro' C draw N C M, perpendicular to the Surface of E F.

Definition III.

620 *The Part* A C *of the ſaid Ray is call'd the incident Ray.*

Definition IV.

621 *The Angle* A C N *is call'd the* Angle of Incidence.

Definition V.

622 *The Part* C B *is call'd the* Refracted Ray.

Definition VI.

623 *The Angle* B C M *is call'd the* Angle of Refraction.

In this Caſe, *When Light goes out of a rare into*
624 *a denſe Medium, the Angle of Refraction is leſs than the Angle of Incidence*, by reaſon of the Inflexion of the Ray; for theſe Angles wou'd be equal, if the Ray A C continu'd to move ſtrait on in the Line C D. The Ray C B does alſo come nearer to the

Per-

Perpendicular C M; and therefore *the Refraction is said* to be *made towards the Perpendicular.*

On the contrary, *if the Ray goes out of a denser into a rarer Medium, it will recede from the Perpendicular*, because the denser Medium attracts the Ray in the same Manner, whether it goes out of a rarer into a denser, or out of a denser into a rarer Medium. Therefore if B C be the Ray of Incidence, CA will be the refracted Ray; that is, 625
Let the Ray come from either Side, and it will move 626
in the same Lines. Therefore, *if there be two Rays,* 627
and one comes out of a denser Medium into a rarer, and the other out of a rarer into a denser, and the Angle of Refraction of the one be equal to the Angle of Incidence of the other, the two remaining Angles of Incidence and Refraction will be equal to each other.

Whence it follows, that *The Direction of the Ray is not chang'd, if it moves thro' a Medium termined by two Surfaces parallel to each other*; for as much as it is turn'd towards any Side at its Entrance, so much exactly is it turn'd the other Way as it goes out of the said Medium. 628

If a Ray falls perpendicularly on the Surface that separates two Mediums, it will not be turn'd out of the right Line by the Attraction of the denser Medium; because in that Case it acts in the Direction of the Ray. 629

Plate IV. *Fig.* 2.] To confirm what we have said by Experiments, take a Trough or open Box P, about a Foot long, 4 Inches wide, and of the same Depth. Its two Sides *a b c d, a b c d,* are Planes of Glass parallel to each other, and this Box must be fill'd with Water two Inches and half high. 630

The Experiments must be made in a dark Place; the Light must be let in thro' a Slit in the moveable round Plate O, which is fix'd to the Win-

Window-ſhut, and is eaſily turn'd round, that the Slit may be inclin'd at Pleaſure: The Slit is 4 Inches long and ¼ Inch wide.

The Light, that is let in, ſtrikes upon the Looking-Glaſs S, and the Slit is ſo inclin'd, and Speculum diſpoſed, that the Beam, that comes thro' the Slit, may be horizontally reflected by the Looking-Glaſs, the Beam being in a vertical Poſition, that it may go thro' a vertical Slit in the Board T, of the ſame Dimenſions as that in the Plate O. This Board is us'd to diminiſh the Breadth of the Beam, which is continually increaſing, by reaſon of the Light that comes from the Sides of the Sun.

Experiment 1.] Things being diſpos'd, as we have ſaid in the Deſcription of the Machine; let the Beam fall perpendicularly on the Surface *a b c d*, and it will paſs perpendicularly thro' the Water and the upper Part of the Trough, and not be turn'd out of the Way at all, either going in or coming out; by which is confirm'd what has been ſaid (N° 629.)

Experiment 2.] Now let the Beam fall obliquely on the Surface *a b c d*, at *f g*; the upper Part of the Beam will continue its Motion ſtrait along *h*; but the lower Part of it, in the Water, will be bent towards *i*, coming towards the Perpendicular; which confirms (N°. 624)

Experiment 3.] Every Thing being, as in the former Experiments, the Beam, which, at *i*, goes out of Water into Air, is turn'd out of its Way fromwards the Perpendicular, and in ſuch Manner, as to move in the ſame Direction as the incident Ray that goes into the Water at *g*; for it goes

goes on parallel to the Ray *f b* continued: which confirms (N°. 625, 626, and 628.)

In what has been said hitherto, we have only consider'd the Attraction of the denser Medium, because it overpowers; but we must not overlook the Action of the rarer Medium, because it diminishes the Action of the denser, which Action becomes so much the less on the Rays of Light, as the Mediums differ less in Density. Therefore *there is no Refraction where the Densities of Me-* 631 *diums are equal; and the Refraction is greatest where the Densities of Mediums differ most.*

The Laws of Refraction are deduc'd from the Acceleration which the Attraction generates; therefore this Acceleration must be examin'd.

Definition VII.

The Space, terminated by the Planes G H *and* 632 I L, *is called the Space of Attraction.*

Plate 4. *Fig.* 1.] The Attraction acts between the Planes represented by these Lines but no farther*. * 619

The Direction of this Action is perpendicular to 633 *the Surface that separates the Mediums, and consequently to the Surface* I L; *and its Form is unequal at different Distances from the Surface*. But* * 619 *it is equal at equal Distances,* because both Mediums are supposed homogeneous, and alike in all their Parts.

The Motion of the Ray A C may be resolved into two other Motions, according to the Directions A O and O C*, of which the first is * 192 parallel to the Surface E F, and the second perpendicular to that Surface: The Celerities of which Motion will be respectively proportional to those Lines A O and O C, whilst A C denotes the Celerity of the Ray itself*. * 192

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634 *The Motion, according to the Direction* AO, *is not chang'd by the Attraction perpendicular to the Surface* I L, *only the Motion according to* O C *is accelerated.*

635 Keeping the Line A C, that is the Celerity of the Ray, its Inclination may be chang'd, whereby also the Celerity in the Direction O C is also chang'd; which Celerity wholly vanishes, if the Angle A *a* G be very small. In which Case, if after Light has enter'd into a denser Medium, its Motion be resolv'd into two, so that the Direction of the one be perpendicular to the Surface I L, its Celerity must be wholly attributed to the Attraction so often mention'd. For, as it enters into the Space of Attraction, a Motion is generated in that Direction; and, as it goes thro' that Space, in which a new Action does every where act upon the Light in the same Direction, it is continually accelerated. Which Acceleration obtains in every Passage of Light thro' the Space of Attraction; but it is different, according to the different Celerity with which Light comes perpendicular to the Surface which parts the Medium.

If the Attraction was equable thro' the whole Space of Attraction, the Laws concerning the said Attraction might be determin'd (as was said of the Acceleration of heavy Bodies after N° 130.) by Help of the rectangular Triangle P Q R, (*Plate* IV. *Fig.* 3.) in which the Lines parallel to the Base represent the Celerities, whilst Portions of the Area of the Triangle represent the Spaces gone thro'.

But here we have always the same Space run thro', namely the Breadth of the Space of Attraction, because we only consider the Motion which is perpendicular to the Surface, which separates the Mediums; therefore that Space is always represented by equal Parts of the Area of the Triangle P Q R. Let P *d c* represent such a Part

Part when the Celerity is equal to *o*. The Light enters the Space of Attraction in the above-mention'd perpendicular Direction, that is, when an incident Ray makes a very small Angle with the Surface that separates the Mediums; *d c* in that Case will denote the Celerity acquir'd by the Attraction, and with which the Light goes out of the Space of Attraction.

But if the Light goes perpendicularly into the Space of Attraction with the Celerity that is express'd by *f g*, it will go out of that Space with the Celerity *b i*, supposing the Areas P *d c* and *f g i b* equal to one another, as appears from what has been said. The Triangle P *d c*, P *f g*, P *b i* are Similar, and therefore their Areas are to one another, as the Squares of the homologous Sides *d c*, *f g*, *b i*; but the Sum of the Areas P *d c*, P *f g*, is equal to the Area P *b i*; (by reason of the equal Areas P *d c* and *f g i b*;) therefore also the Sum of the Squares of the Lines *d c* and *f g* is equal to the Square of the Line *b i*; whence it follows, that with the three Lines above-mentioned one may form a rectangular Triangle, whose Hypothenuse will be *b i*.

Therefore, *In a rectangular Triangle, one Side of* 636 *which is the Celerity with which Light enters the Space of Attraction perpendicularly, and the other Side the Celerity acquir'd in going thro' that Space, when the Celerity with which the Light enters into it is equal to* o; *the Hypothenuse of the Triangle will be the Celerity with which the Light goes perpendicularly out of the Space of Attraction on the other Side:* Which universally obtains, which way so ever the Attraction is chang'd, in the Space of Attraction, according to the different Distance of the Planes that terminate that Space. Which to prove,

Let us suppose the Space of Attraction to be divided into two Parts, whether equal or un-

equal, by a Plane parallel to the Surfaces with which it is terminated. Let us ſuppoſe beſides, that the Attraction is not the ſame in thoſe two Parts, but yet that it does not vary in one of them. Theſe Parts are to be conſider'd as two different Spaces of Attraction. Let A (*Plate* IV. *Fig.* 4.) be the Celerity which the Light acquires in going thro' the firſt Part of the Space, when it enters the Space with the Celerity O. Let B be the Celerity acquir'd in going thro' the ſecond Part of the Space, when the ſame Light enters that Part with the Celerity O. It is to be obſerv'd that this Demonſtration relates to the Motion, perpendicular to the Surface, which ſeparates the Mediums.

Let the Light enter the firſt Part of the Space above-mention'd with the Celerity O, it will come to the ſecond with the Celerity A; if therefore a right angled Triangle be form'd with the Sides A and B, the Hypothenuſe E D will expreſs the Celerity with which the Light will go out of
* 636 the Space of Attraction*.

If the Light enters the Space of Attraction with the Celerity F G, let the rectangular Triangle H F G be drawn with the Sides of F G and A; the Hypothenuſe H G will be the Celerity, with which the Light goes out of the firſt Part of
* 636 the Space of Attraction*, and enters into the ſecond; and if you draw the rectangular Triangle H G I, whoſe Perpendicular is equal to the Line B, you will have the Hypothenuſe I G to denote the Celerity with which the Light goes out, and continues its Motion after it has run
* 636 thro' the whole Space of Attraction*.

Now we muſt demonſtrate that the Celerity I G is alſo the Hypothenuſe of the rectangular Triangle N M L, whoſe Side M L is equal to the Celerity F G, with which the Light enters the Space

Space of Attraction; and whose other Side L N is equal to the Line E D, which is the Celerity that the Light acquires in going thro' the whole Breadth of the Space of Attraction, when it has enter'd it with the Celerity O; which being also demonstrated in that Case, in which two different Forces of Attraction act, it is plain that the Proposition of N° *636* is thereby prov'd.

But it is plain from the Consideration of the rectangular Triangles, that the Lines I G, and N M, are equal. The Square of the Line N M is equal to the Squares of the Lines N L and L M, or F G. N L is equal to the Line E D, whose Square is equal to the Squares of the Lines E C and C D, or of the Lines A and B, which are equal to F H and H I: therefore the Square of the Hypothenuse N M is equal to the three Spuares of the Lines F G, F H, and H I. To which three Squares, the Square of the Lines G I is equal; as having been prov'd equal to the Squares of the Lines H I and H G, which last is equal to the Squares of the Lines H F and F G.

If the Space of Attraction be divided into ever so many Spaces by plain parallel Surfaces, which terminate that Space, and the different Parts have different Forces of Attraction, the same Demonstration will serve; and the Number of Divisions may be made any how *in infinitum*; which Case obtains in the Refraction which Light suffers going out of any Medium into another of different Density*: *to* which *Refraction* therefore *the Rule of* N° 636 *may be applied*. 637

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Plate IV. *Fig* 5.] Let Z be the rarer, and X the denser Medium, and let them be separated by the Plane E F; let a Ray of Light A C fall obliquely on the Surface E F; let A C denote the Celerity of the Light in the Medium Z, and

 let

let that Line A C be settled; that is; let it be always the same, whatever the Inclination of the Ray is. With the Center C and the Semidiameter C A, draw a Circle; and let N C M be drawn perpendicular to E F; from A, draw A O perpendicular to N C, and A Q to E F.

Let us conceive the Motion along A C resolv'd into two others, the one along A O, and
* 192 the other along A Q or O C *; the Line O C will denote the Ray's Celerity perpendicular to the Surface E F, which Celerity alone is increased
* 634 by the Attraction of the Medium *.

Let C P be the Celerity which Light acquires, in passing perpendicularly thro' the Space of Attraction of the Medium X; supposing the Celerity of Light at its Entrance to be O, the Hypothenuse O P of the rectanglar Triangle P C O will be the Celerity of the Ray A C in the Medium X, according to a Direction perpendi-
* 637 cular to the Surface E F*; the Celerity of the Light in the Direction A O or Q C, parallel to
* 634 the Surface E F, is not chang'd*. Therefore let C V be equal to A O or Q C, and V B perpendicular to E F, equal to the Hypothenuse P O, and draw C B; the Motion along C B is compounded of the Two, and this Line by its Situation determines the Direction, and by its Length
* 190 *the Velocity of the Light in the Medium* X*; which
638 Celerity *is not chang'd by the different Inclination of the Ray* A C. For the Square of the Line C B is equal to the Square of the Line B V or P O, the Square of the Line C V or A O; but the Square of the Line P O is equal to the Squares of the Line P C and C O: Therefore the Square of the Line C B is equal to the three Squares of the Lines P C, C O and A O; which two last, if join'd, will give us the Square of the Semidiameter A C or C N; that is, C B is equal

to

to P N, whose Square is also equal to the Squares of the Lines P C and C N, and which undergoes no Change from the different Inclination of the Ray A C.

The Line C B does in T cut the Circle, which is describ'd with the Semidiameter C A; from the Points B and T, draw B S and T R perpendicular to C M; by reason of the Similar Triangles C B S, C T R, B C will be to T C or C A, as B S to T R; which Lines therefore, by reason that B C and C A are settled, will have the same Ratio to one another, whatever be the Angle of Incidence. T R is the Sine of the Angle of Refraction T C R, and B S which is equal to C V, that is equal to A O, is the Sine of the Angle of Incidence A C O.

Therefore, *in every Inclination of the Incident Ray, there is a settled and constant Ratio between the Sines of the Angles of Incidence and Refraction.* 639

Now since B C and C A, which are as the Sines above-mention'd, do also denote the Celerities of the Light in *the* Mediums X and Z, it follows that those *Sines are inversly, as the Celerities in the Mediums.*

If the Medium Z be Air, and X Water, the aforesaid Sines are as 4 to 3; and the Celerity of the Light in Air to its Celerity in Water, as 3 to 4. But if Z being still taken for Air, X be Glass, the Sines will be as 17 to 11. One Experiment determines this for all Mediums. 640

The Ratio between the Sines of any Angles is the inverse Ratio of the Secants of the Complements, as it appears in this Figure, supposing a Circle drawn with the Semidiameter C Q or C V; for then A C (which is equal to C T) and C B will be the Secants of the Angle A C Q, and B C V Complements to the Angles of Incidence and Refraction, and inversly, as B S (which is 641

 equal

equal to A O) and T R, which are the Sines of Incidence and Refraction in the greater Circle.

And this Proportion of the Secants gives us a Method of easily reducing to Experiment the *Prop.* of N°. 639.

Experiment IV. *Plate* IV. *Fig.* 6.] In this Experiment the Light is to be let into the dark Chamber thro' a Slit in the same Manner as in the former Experiments, and by means of a Looking-Glass reflected thro' the vertical Slit in the Board T.

Take a Trough P, nearly of the same Size as that which was us'd in the former Experiments, but which has only one End of Glass, namely, the little Side *a b c d*. And let it be half fill'd with Water.

The vertical Beam of Light being made to fall obliquely on the Glass End of the Trough, the Part of it, which is above the Water, and goes directly forwards, and at *b* falls upon one of the long Sides of the Trough; but that Part of the Beam, which is refracted in the Water, goes along *g i*, and strikes against the same Side of the Trough at *i*. Whatever the Angle be which the Beam makes with the End or Side *a b c d*, the Lines *f b* and *g i* will always be to each other, as 3 to 4; as is very easily shewn in several Inclinations, if you have two Scales, each with small Divisions on them; which Divisions in the one must be to the Divisions in the other, as 3 to 4: For the greater Line *g i* will always contain as many of the great Divisions, as the lesser Line *f b* will contain of the small ones. The Angle, which *f b* makes with the Plane *a b c d*, is the Complement of the Angle of Incidence to a right

a right Angle; and the Angle made by the Line *g i* with the same Plane is the Complement of the Angle of Refraction to a right Angle; therefore *g h* and *g i* are the Secants of the Complements of the Angles of Incidence and Refraction, which have a constant Ratio to one another, as was to be confirm'd by this Experiment.

We have hitherto consider'd a Ray of Light 642
going out of a rarer into a denser Medium, but the same constant Proportion of the Sines mention'd, Nº 639, holds good also in the contrary Motion of the Rays; the Angles A C N, M C B (*Plate* IV. *Fig.* 5.) are not chang'd, whether the Incident Ray be A C or B C*. In that Case, if BC be the Celerity of the incident Ray, C A will be the Celerity of the refracted Ray; for the Motion of the Ray, going out of X into Z, is retarded in the same Manner by the Attraction towards the Medium X, as it is accelerated in the contrary Motion.

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CHAP VII.

Of the Refraction of Light, when Mediums are separated by a plane Surface.

Definition I.

RAys *proceeding from the same Point, as a* 643
Center, and continually receding from each other, are said to be divergent.

Definition II.

Those diverge more, *which make a greater* 644
Angle with each other.

Definition III.

645 *The Point, from which the divergent Rays proceed, is call'd the* Radiant Point.

646 *The more the Rays diverge, supposing them at equal Distances from each other, the less is the*
647 *radiant Point distant from them; and so on the contrary,* the Rays are often mov'd by *Refraction*, as if they came from a radiant Point, tho' they do not really proceed from such a Point; that is, if the Rays should be continued or produced back the Way from whence they come, they would meet in one Point. In that Case also, the Rays are said to be divergent.

Definition IV, and V.

648 Rays *which concur in one Point, or would concur if they were continued, are said to be* convergent;
649 *and those are* more convergent, *which make greater Angles between themselves.*

Definition VI.

650 *The Point of the Concourse of converging Rays, is call'd the* Focus.

Definition VII.

651 *The Point, in which converging Rays, and such as (being intercepted or turned out of the Way before their Concourse) would have concurred, being continued, is called the* imaginary Focus. Which Name is also given to that Point from which those divergent Rays are conceived to flow,
* 647 which do not proceed from the radiant Point*.

652 *The more the Rays converge, supposing their Distance from each other to be the same, the less Distance from them is the Focus, whether real or imaginary.*

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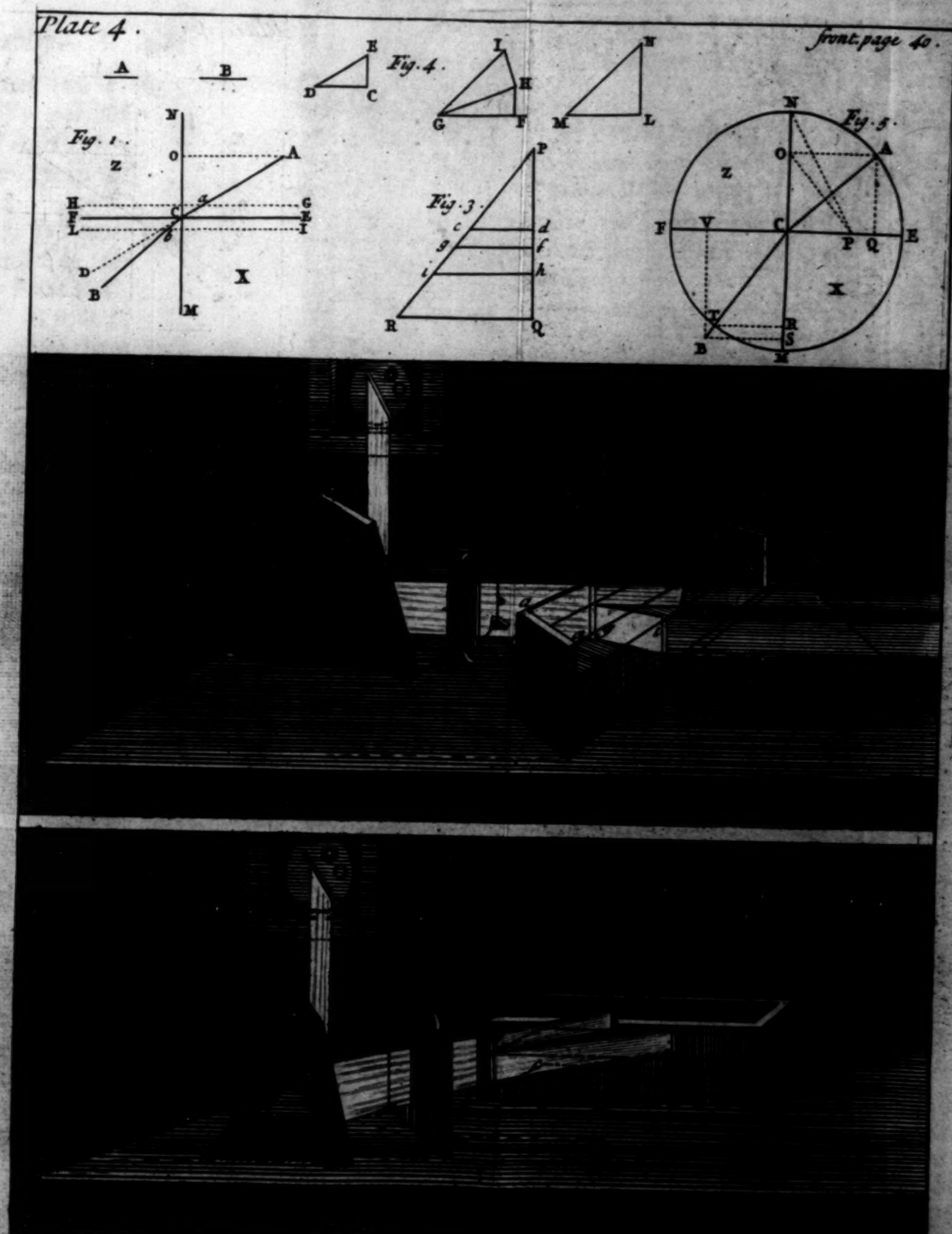

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If parallel Rays pass out of any Medium into another of different Density, they will also be parallel after Refraction: Because they are all equally inflected; for in all this Chapter, we speak of Mediums separated by a Plain Surface. 653

Let X *and* Z *be two Mediums, the last more rare, and the other more dense, separated by the Plane* E S, (*Plate* V. *Fig.* 1.) *from the Point* R C, *let there proceed the divergent Rays* P C, R *o*, R *n*, *and enter into the denser Medium:* Let one of them be R C, perpendicular to the Surface E S; this last is not turn'd out of the Way *, but continues its Motion along C G. The Rays R *o*, R *n*, are refracted towards Perpendiculars, which are conceiv'd to fall upon the Surface E S in the Points *o* and *n* *. *These Rays are mov'd in the denser Medium, as if they all proceeded from the imaginary Focus r, which is farther distant from the Surface than* R, *if the Rays are not too much scattered;* which yet is not to be understood Mathematically; for, by a Point, we understand a small Space, such, as is otherwise call'd a Physical Point. 654 * 629 * 624

To demonstrate this Proposition, we must consider, that the Angle R *o* C, is the Complement of the Angle of Incidence to a right Angle; and that the Angle *r o* C is also the Complement of the Angle of Refraction to a right Angle; and therefore that the Lines R *o*, *r o*, are the Secants of the Complements of the Angles of Incidence and Refraction, supposing the Semidiameter to be *o* C; between which Secants, there is a constant Proportion *. In the small Divergence R *o* and R C, as also *r o* and *r* C, they do not sensibly differ, and between R C and *r* C, the Ratio is always constant; that is, *r* is fixed as well as R, tho' the Inclination of the * 641 639

Ray

Ray be chang'd: And therefore R *n* is refracted along *n* A, as if it had proceeded from *r*.

655 *If the Rays are too much dispers'd*, this Demonstration will not serve, and the Place of Concourse *r* cannot be taken for a Point: In this Case *a little Circle must be imagin'd* there, *into which all the Rays concur, which will be the greater, the greater the Angle is that the divergent Rays make.*

656 *If some Rays, proceeding from* R, *are not too much dispersed, but fall very obliquely on the Surface* E S, *they will be refracted, as if they proceeded from a Point not very remote from the Point r:* As is plain from what has been said.

657 *The Rays*, such as A *n*, B *o*, G C, *which come converging from a denser Medium* X *into a rarer* Z, concur sooner than they wou'd do, if they shou'd
* 625 continue their Motion in a denser Medium *, that is, *become more convergent*, and the real Focus is less distant than the imaginary one. In this Figure, the imaginary Focus is *r*, and the
* 625 real Focus R *. This Proposition therefore is properly the Inverse of the Proposition of N° 654.
* 626 and therefore * both are prov'd by the same Experiment.

Experiment 1. *Plate* V. *Fig.* 2.] Thro' the Ball G, which is moveable in the Window-shut, and has an Hole going thro' the Middle of it, let a cylindric Beam of the Sun come into the dark Room, and be reflected horizontally by the Looking-Glass S; let it then go through the Convex Lens of Glass that is fix'd in the Board or Stand T, and the Rays will meet together at R, and beyond R will move as if they proceeded from that Point; which therefore is the radiant Point.

Convex

Convex Lenses of Glass are very common; we shall hereafter mention their Properties*, it being needless to do it in this Place: Now we only want a radiant Point, and it is enough to shew how to make it. * 691 697

Take a Trough Box P, whose Side *a b c d* is of Glass, and let it be fill'd with Water: The Rays, which diverge from the Point R, become less diverging when they go into the Water.

When convergent Rays as H D, I *p*, L *q* (*Plate* V. *Fig* 1.) having their imaginary Focus at *f*, *go from the rarer Medium* Z *into a denser* X, *they become less convergent**, and concur in the Focus F, which is more distant from the Surface E S *, as appears by applying here the Demonstration given in N°. 654. 658 * 624 * 652

Rays proceeding from the Point F, *and going out of a denser Medium into a rarer*, *become more diverging*, and move as if they came from *f*, which Proposition is the Inverse of the foregoing, and is confirm'd by the same Experiment *. 659 * 626

Experiment 2. *Plate* V. *Fig*. 3.] Take the same Box B, as was used in the former Experiment; but here let in two Beams of the Sun into the dark Room thro' two Holes in the moveable Plate in the Window-shut; let them be both reflected horizontally, and transmitted thro' similar convex Lenses; thereby the Rays of the Beams will become convergent, having their Focus's at the same Distance; but if the converging Rays are made to run into the Water in the Box thro' the Side *a b c d*, they will be collected at a greater Distance; which will plainly appear by comparing together the Situation of the Points F in the Air, and *f* in the Water.

CHAP.

CHAP. VIII.

Concerning the Refraction of Light when a spherical Surface separates the Mediums.

Plate VI. *Fig.* 1.] LET X and Z be Mediums differing in Density, the last the rarer, and the first the denser; let them be separated by the spherical Surface E S, whose Center is C, and whose Convexity is towards the rarer Medium.

660 To begin, by examining the most simple Case; *Let us suppose parallel Rays*, as B O and A *n*, *going out of a rarer into a denser Medium, and falling upon a convex Surface*, such as we have just describ'd; let one of them be B O, which, being continu'd, goes thro' the Center, and falls perpendicularly upon the Surface E S; and there-

* 629 fore is not turn'd out of the right Line *. All *the Rays, which are not too distant* from that Ray, come nearer to it by the Refraction of the denser Medium, and *are collected into one Point* F: As for Example; Let A *n* be a Ray which is refracted along *n* F; thro' the Point *n* draw to the Center C the Semidiameter C *n*, and let it be continu'd to *p*; as this Line is perpendicular to the Surface which separates the Mediums, the Angle of Incidence is A *np*, which is equal to the Angle *n* C O; the Angle of Refraction is C *n* F. If the Arc *n* O be a very small one, these Angles are as their Sines, whose Ratio is constant *. Therefore these Angles *n* C O and

* 639 C *n* F are increas'd and diminish'd in the same Ratio, as long as their Difference, which the Angle *n* F O, which consequently follows the Proportion of the Arc *n* O, which is the Measure of the Angle *n* C O; as long as the Arc *n* O does

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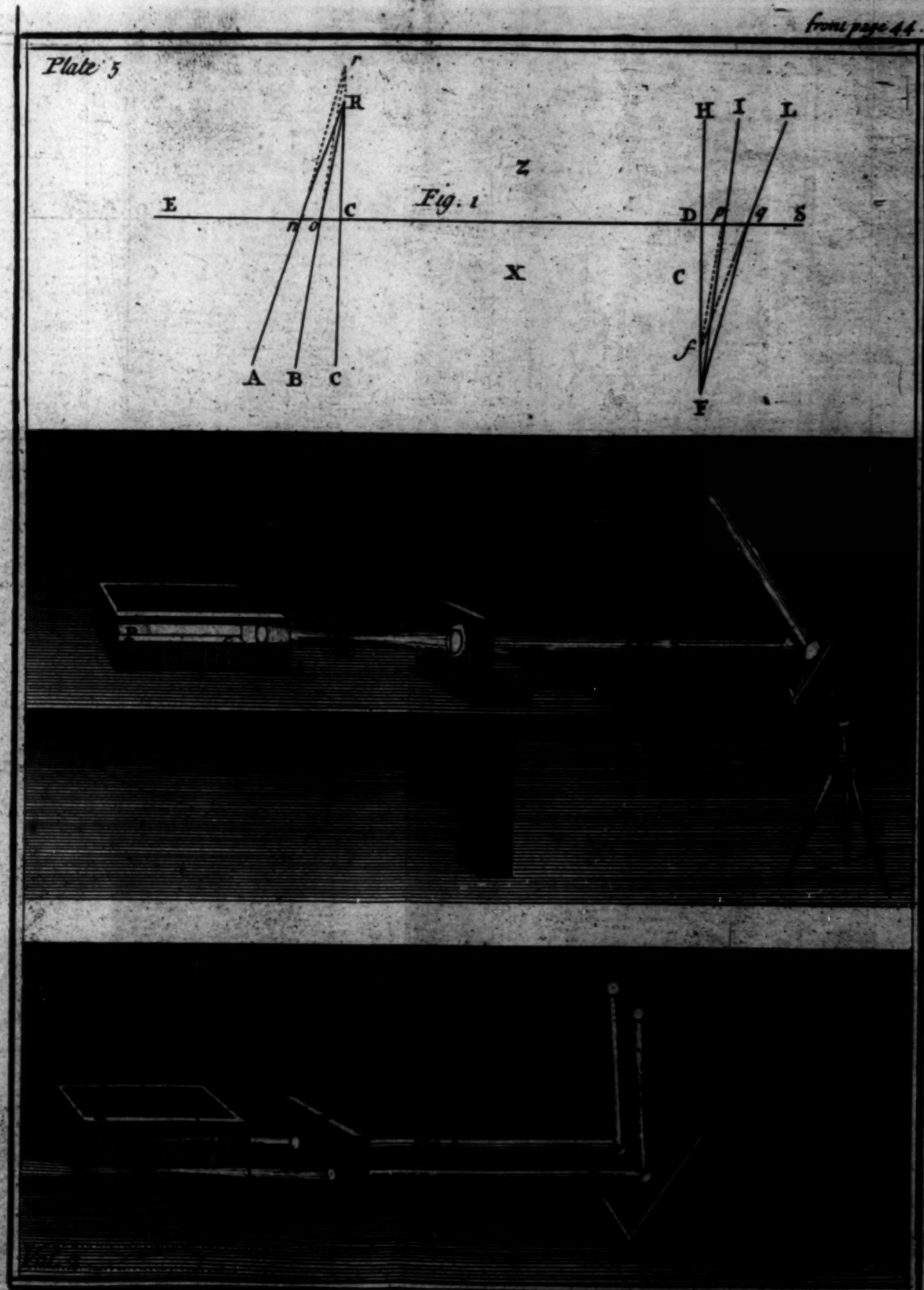

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does not exceed 15 Degrees, the Angle *n* F O is increaſed and diminiſhed ſenſibly in the ſame Ratio, as the ſaid Arc; and therefore all the Rays, between A *n* and B O, do by their Refraction meet ſenſibly in the Point F.

Experiment 1. *Plate* VI. *Fig.* 2.] Let a cylindric Beam of the Sun, of an Inch in diameter, made up of innumerable parallel Rays (which are ſo on account of the Sun's immenſe diſtance) be let into the dark Room, as in the firſt Experiment of the foregoing Chapter, and be reflected horizontally by the Looking-glaſs S.

Fill with Water the Trough P, which is about 3 Inches high, and as wide, and one Foot long; let it have a Glaſs V made faſt in one of its Sides; this Glaſs muſt be a Portion of a Sphere, thin, and every where of the ſame thickneſs, ſuch as the Cryſtal of a Pocket Watch.

The convex Part of the Glaſs V muſt be outwards, that the Water next to it in the Trough may put on a ſpherical Surface; if the Rays above-mention'd go into the Trough thro' this Glaſs, becauſe the Glaſs is thin, and has its Surfaces parallel, there is no ſenſible Change in the Motion of the Light by the Refraction of the Glaſs, and the Light enters into the Water in the ſame manner as if there was no Glaſs; let the Trough be ſo diſpos'd, that one of the Rays may paſs thro' the Center of the ſpherical Surface, and the others will come nearer and nearer to it, and at laſt concur with it at F.

Plate VI. *Fig.* 3.] Again, let X be the denſer Medium, and Z the rarer, and let them be ſeparated by the ſpherical Surface E S, whoſe Center is at C, and whoſe Convexity is towards the rarer Medium: *From the radiant Point* R *let Rays pro-* 661
ceed,

ceed, and enter into the denser Medium thro' the Surface above-mention'd; so that of those Rays, that which is expreſs'd by R O, being continu'd, may paſs thro' the Center; this Ray is not refracted as it goes into the Water, and all the reſt of the Rays come towards it by the Refraction, *and when they are not too divergent are collected into one Point* as F, in the ſame manner as was ſaid of parallel Rays, with this difference, that the Focus F in that Caſe is more diſtant. The ſame Demonſtration will alſo ſerve here as relates to parallel Rays, which is built upon this Foundation, that the Angle of the Incidence increaſes in the ſame Ratio as the Arc *n* O, which does alſo obtain here, when the ſaid Arc does not exceed 15 Degrees. Let R *n* be a Ray of Light, and from the Center C thro' *n* draw C *n p*; the Angle R *n p* will be the Angle of Incidence; let it be divided into two Parts by the Line *n q*, parallel to the Line R O C; the Part *p n q* is equal to the Angle *n* C O, which is meaſur'd by the Arc *n* O, and which therefore follows the ſame Proportion as that Arc; and which alſo the Angle *n* R O (if it be very ſmall) does follow, and is equal to the ſecond Part of the Angle of Incidence, which alſo does wholly increaſe and diminiſh in the ſame Ratio as the Arc *n* O; for the Ratio which holds in reſpect of every Part, taken ſingly, will alſo hold in reſpect of the whole.

662 The ſame Demonſtration may be applied to any diverging or converging Rays, which in any Caſe are refracted in paſſing thro' a ſpherical Surface, and which (as appears by this Demonſtration) when they diverge but little, have their Focus real, or imaginary, or run parallel. It is enough to have obſerv'd this in general.

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The Focus F *of the Rays that come from* R, *goes* 663
farther off when R *is brought nearer*; *and so on the contrary.* For the radiant Point being brought nearer, if the Point *n* remains the same, the Angle of Incidence is increased; and as it increases, so does also the Angle of Refraction F *n* C, and *n* F intersects R C at a greater distance.

Experiment 2. *Plate* VI. *Fig.* 4.] This Experiment differs from the foregoing only in this; that a cylindric Beam of the Sun reflected horizontally, must be transmitted thro' the convex Lens in the Board T, as was done in the Experiments of the foregoing Chapters, to form the radiant Point R, from which the Rays, going forward, diverging, are collected in the Water at a greater distance than if they had been parallel.

As you move the Board T, the Point R also changes its place; if this Point is farther off from the Surface that separates the Mediums, F falls nearer to it; on the contrary, if R be nearer, F is farther off.

The radiant Point may be brought so near to the 664
Surface above-mention'd, that the Focus will recede to an infinite distance; that is, *that the refracted Rays will run parallel.*

Experiment 3. *Plate* VI. *Fig.* 5.] Things being dispos'd as in the former Experiment, by removing the Board T, let R be brought nearer to the Trough, and it may easily be so dispos'd as to make the refracted Rays become parallel.

Experiment 4. *Plate* VII. *Fig.* 1.] Now if the 665
Experiment be repeated, *bringing nearer* to the Trough *the radiant Point* R, *the refracted Rays will become divergent, but they will diverge less than the*

666 *the incident Rays. If the Rays, which out of a rarer enter into a denser Medium thro' a convex Surface, be converging and directed towards the Center of that spherical Surface, they will suffer no Re-*
* 629 *fraction**; *but if they be directed towards another*
667 *Point*, since they are refracted towards the Per-
* 624 pendicular*, they will be so inflected, that the Focus of these converging Rays will always be between the Center of the Surface which separates the Mediums (to which all the Perpendiculars are directed) and the Point to which the incident Rays tend; *that is, if the imaginary Focus of the incident Rays be at a less distance than the Center, the refracted Rays will be less converging; but if this imaginary Focus be beyond the Center, the refracted Rays will be more converging.*

Experiment 5. *Plate* VII. *Fig.* 2.] Every thing being in the same manner as in the former Experiments, it is easy to confirm these Propositions by Experiments; for the Board T may be so dispos'd, that the convergent Rays shall enter the Water, so as to have their imaginary Focus at any distance in it.

668 From what has been said hitherto it is easy to determine what happens *in a contrary Motion of*
* 626 *the Rays**; that is, the Motion of the Rays from a denser into a rarer Medium, *the convex Surface remaining towards the rarer Medium.*

Parallel Rays, after Refraction, concur in a
* 644 *Focus**:

669 *The Rays that come from a radiant Point meet*
* 661 also *in a* Point or *Focus**, and as that Point is brought near, the Focus goes farther off; and so
* 663 the reverse on the contrary*.

670 *The radiant Point may be so placed, as that* the Focus shall fly out to an infinite distance; that is,
* 660 *the Rays will become parallel**.

front page 46.. *Plate 6.*

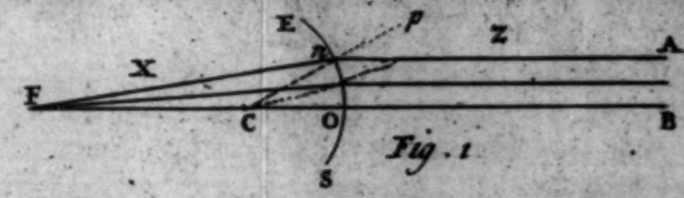


Fig. 1

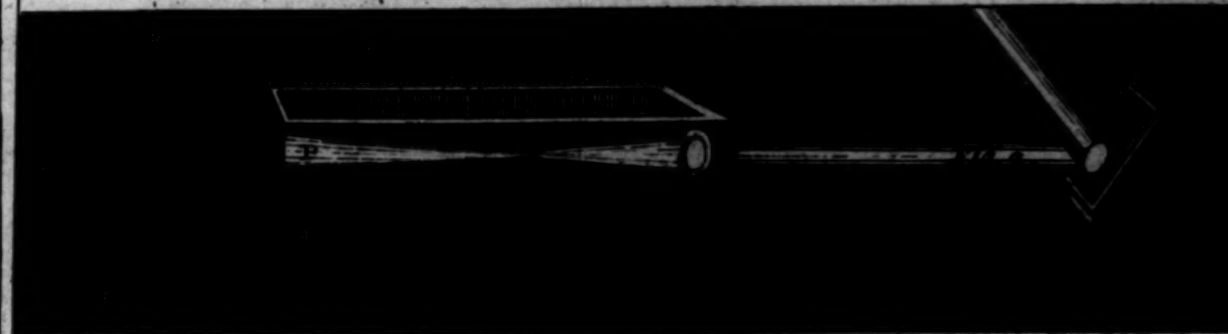
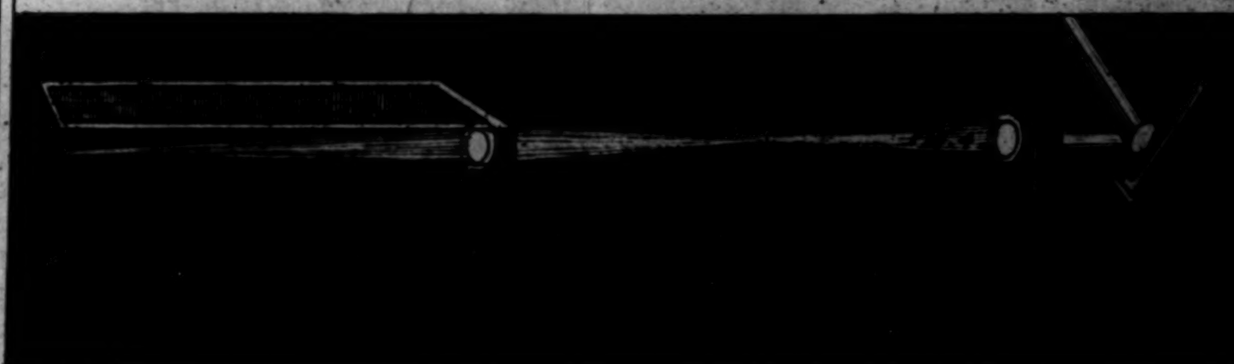


Fig. 3



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If the radiant Point be brought nearer, the refracted Rays will diverge; they *will diverge less than the incident Rays, if the radiant Point be more distant from the Surface than the Center**. 671 * 667

But *if the radiant Point be between the Surface and the Center, the refracted Rays will be more divergent**. 672 * 667

If the Rays are convergent, they become more convergent in every Case, which follows from the Refraction being made fromwards the Perpendicular*, and which may be also deduc'd from N°. 665. 673 * 625

Plate VII. *Fig.* 3.] *Let us* again *suppose the Rays to go out of the rarer Medium* Z *into the denser* X, *and that the Hollow or Concave of the spherical Surface* E S, *which separates the Mediums, is towards the rarer Medium.* If the Rays be *parallel*, as B O, A *n*, B O, which goes thro' the Center C of the Surface E S, will not be refracted; but A *n* is refracted towards the Perpendicular C *p* along *n* G*, and, being continued towards Z, intersects B C O at *f*, which is also true in respect of the *Rays between* B O and A *n**; those Rays therefore *become divergent*, having their imaginary Focus *f* in the rarer Medium. 674 * 624 * 662

Experiment 6. *Plate* VII. *Fig.* 4.] This Experiment differs from the first of this Chapter, only in this, that the Glass V has its Concavity towards the Air, the Trough P being in all other Respects the same; in this Case the Rays of the cylindric Beam diverge in the Water.

If Rays come from a radiant Point in C B, *which is beyond* C (*Plate* VII. *Fig.* 3.) the Angle of Incidence A *n* C is diminish'd, and therefore also the Angle of Refraction G *n p* grows less; that is, *the refracted Rays become more diverging,* and the 675

* 646 imaginary Focus *f* comes nearer to C*; till by the radiant Point coming nearer, at length it coincides with the imaginary Focus at C; for in
* 629 that Case the Rays undergo no Refraction *.

676 If the radiant Point comes nearer between C and O, the imaginary Focus is farther from O than the radiant Point, for it is always between that Point and C, by reason of the Angles of Re-
* 624 fraction being less than those of Incidence*.

Experiment 7.] Things being, as in the former Experiment; if you use the Board, with the Convex Lens in it, to form a radiant Point, the Experiments proving these Propositions may be easily made.

677 *If the Rays are converging, and the Point of Concourse be in the denser Mediums, near the Surface which separates the Medium, the refracted Rays* will also *converge*, but *less than the incident Rays.*

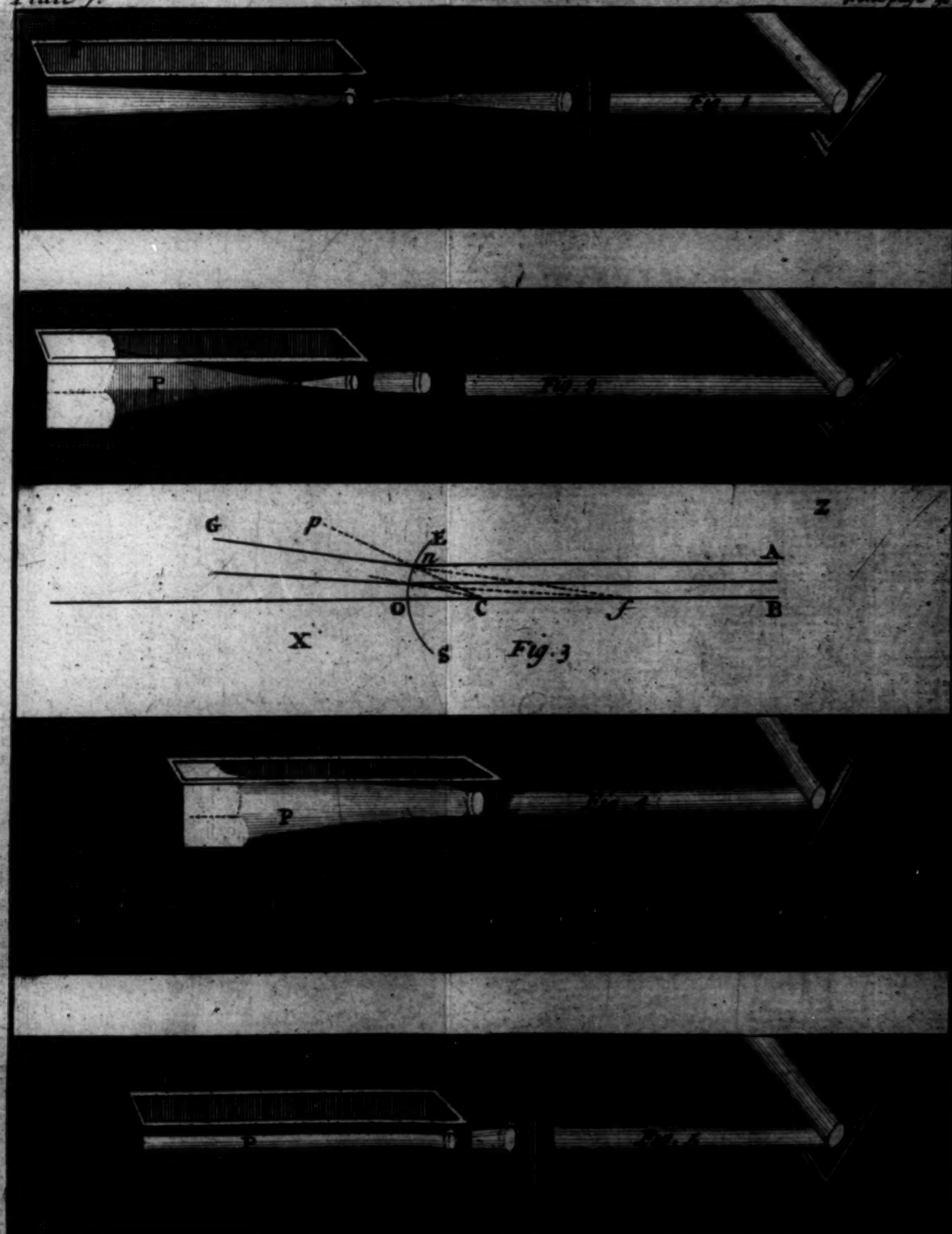
678 If the imaginary Focus of the incident Rays recedes more and more from O, that is, *if they converge less, the refracted Rays will also converge less; until, by the receding of the imaginary Focus, the Rays become parallel.*

679 *If the imaginary Focus recedes yet farther, the refracted Rays become divergent.*

Experiment 8. *Plate* VII. *Fig.* 5.] Here the Board must be so plac'd in respect of the Trough, that the Rays may enter the Water converging; and the Phænomena above-mention'd may be seen, according as you remove the said Board.

680 Rays which *from a denser go into a rarer Medium, the concave Surface being towards this last,* are almost subject to the same Laws.

* 678 *Parallel Rays by Refraction become divergent*.*
626
681 *If they proceed from a radiant Point, they become more divergent*.*
* 677


G
p
E
n
A
O
C
f
B
X
S
Z
Fig. 3

And they diverge still more and more, as the radiant Point is brought nearer *. 682
* 678

Converging Rays, which tend to the Center of the spherical Surface, undergo no Change *. 683
* 629

If they converge more or less, the imaginary Focus of the incident Rays is always between the Center of the Surface, which separates the Mediums, 684 685 *and the Focus of the refracted Rays,* * *which may recede* in infinitum, *so as to make the refracted Rays become parallel* *. 676
* 675
* 674

We have hitherto consider'd such Rays as are but little inclin'd to the Surface which separates the Mediums; for we have mention'd such incident Rays as diverge but little, and one of which is perpendicular to the Surface that separates the Mediums. *The same Propositions hold good in oblique Rays,* yet *in that Case all the Rays are inflected*, which does not happen so in direct ones; for the Ray which is perpendicular to the Surface is not inflected. Oblique Rays also undergo a greater Refraction, that is, *they are more inflected either to or from each other*, than direct ones, supposing the Circumstances the same. 686 687

Plate VIII. *Fig.* 1.] Let Z be a rarer, and X a denser Medium, E S the Surface separating the Mediums, and having its Center at C; and the parallel Rays A *n*, B *m* will come together at F. The Rays that proceed from the radiant Point R will concur at F.

Plate VIII. *Fig.* 2.] If the Surface be turn'd so as to have its Concavity towards the rarer Medium, the parallel Rays A *n* and B *m* will have their imaginary Focus at *f*; but its Distance from the Surface E S, as also that of the above-mention'd Foci F and *f* in the *Figure* 1. is less, than if the Rays were direct.

688 *All the Points of a lucid Body are radiant Points, and have each their particular Focus*, which serves to explain the following Experiment, made to confirm what has been said of the oblique Rays.

Experiment 9. *Plate* VIII. *Fig.* 3.] Take the Trough P mention'd in the first Experiment, and fill it with Water; let the Glass V be all cover'd, but a circular Part in the Middle of about half an Inch; have in the Trough a moveable white Plane T. If the Candle A be set at the Distance of 3 or 4 Foot from the Trough, let the Plane T be mov'd backward and forward in the Water, and when it is come to the Distance of the Foci of the Flame A, that Flame will appear exactly represented on that Plane, all the Foci forming a Picture. And this holds good, whether the Rays from the Candle fall obliquely or directly upon the Glass V, only that when the Rays are oblique (the Distance of the Candle A remaining the same) the Distance of the Plane T from V must be less. In this Case also the Candle and the Glass V will not be in the same right Line as the Representation of it, as it happens when the Rays are direct, by which the Proposition of Nº. 686. is confirm'd.

689 *The Candle is represented inverted*, because the Rays, which proceed from different Points, intersect one another as they go thro' V, as may be plainly seen by looking at the first Figure. For which Reason, if there are two Candles, as A and B, the Representation of the last will be at *b*, and that of the first at *a*.

690 *All the Changes that happen in Light*, which we have taken Notice of in this Chapter, *are so much the more sensible, as the Surface separating the Mediums is* more curve; that is, *a Part of a lesser Sphere.*

CHAP.

CHAP. IX.

Concerning the Motion of Light thro' a more dense Medium. Where we shall take notice of the Properties of Lenses.

THE Use of Glasses is common, they are 691
more dense than Air, and the Rays out of Air pass thro' the Glass into Air again. According to the several Surfaces that terminate the Glass, Light undergoes different Changes as it moves in it; which to determine, the Glasses, or any Mediums encompass'd with a rarer Medium, and terminated with different Surfaces, must be examin'd. *If we consider only plane and spherical Surfaces, there are six Sorts.*

The Medium may be plane or flat on both Sides. 2. Plane on the one Side and convex on the other. 3. Convex on both Sides. 4. Plane on one Side and concave on the other. 5. Concave on both Sides. 6. *Lastly*, It may be terminated with a concave Surface on one Side, and a convex one on the other.

DEFINITION I.

If the Glass be made use of, and is not very 692
thick, Glasses, whose Figure is mention'd in the last five Cases, are call'd *Lenses of Glass*.

In the second and third Case, a Lens is said to be convex; and if we distinguish those two Cases, in the second it is call'd *plano*-convex. And so in the fourth Case, it is said to be *plano*-concave; tho' both this Case, and the fifth, is generally referr'd to concave Lenses. But a *concavo*-convex Lens is referr'd to the concave or convex Lenses, according as the one or the other Surface is predominant; and that is said

to be predominant which is most curve; that is, which is a Portion of a less Sphere.

DEFINITION II.

693 *In every Lens, or Medium, terminated in any Manner above described, a right Line, which is perpendicular to the two Surfaces, is call'd the* Axis. When both Surfaces are spherical, the Axes goes thro' both their Centers; but if one of them be plane, it falls perpendicularly upon that, and goes thro' the Center of the other.

694 In the Passage of Light thro' a Medium, terminated by two plane Surfaces, *the Direction of* * 628 *the Rays is not changed**; which is the Case *in plane Glasses.*

695 *It is the Property of all Sorts of convex Lenses, that the Rays in their Passage thro' them are inflected towards one another; so much the more, as* 696 *the Convexity is greater: And so concave ones, that the Rays are deflected from one another, according as the Concavity is greater.* For the Direction of * 694 the Rays thro' a plane Glass is not changed;* but, by inflecting one or both Surfaces, another Direction is given to the Rays: There are more inflected towards the Axis of the Lens, by reason of the Convexity of the Surface of the Glass, and, by making the Surface concave, they are deflected from the Axis; as is plain in every Case, by comparing the Inflection in the plane Surface that is perpendicular to the Axis, with the Inflection in the spherical Surface at any Distance from the Axis. And the Difference of their Inflections, that is, the Change of the Direction of the Rays, increases, as their Distance from the Axes does; and it is to be observ'd in every Direction of the Rays, as well in oblique Rays, as in direct; but *the Changes are greater in oblique Rays,* because the Angles of Incidence are greater; from which 697 we deduce the following Properties of Lenses.

That

That *parallel Rays, by passing thro' a convex Lens, concur in a Focus.* 698

That *diverging Rays either diverge less, or run parallel, or lastly, converge; in which Case, the radiant Point receding, the Focus comes nearer, and so on the contrary:* But this is the Case when the radiant Point is farther distant from the Lens than the Focus of parallel Rays. 699

Lastly, that *converging Rays converge more when the Light emerges out of the Lens.* 700

The same things are observable in oblique Rays, concerning which it is to be noted, that the Distances of the Foci of the emerging Rays are less than in the direct, and the other Changes more sensible.* 701

* 697

All these same things may be deduc'd from examining the double Refraction in the Entrance and Emersion of Light; and this double Refraction is visible in every Case, by the following Experiments; by which the aforesaid Properties of convex Lenses are confirm'd.

Plate VIII. *Fig.* 4.] Take several Boxes like P, with Water in them, and thro' which Light is transmitted thro' the Glasses V and V, which are placed in the opposite sides of the Box, and are distant from one another about one Inch; these Glasses are thin. In the Box, which represents a convex Lens, on each side there is placed one, like that of the first Experiment of the former Chapter, which are so disposed as to have their Convexities without the Box; when a *plano*-convex Lens is to be represented, on one side there is a plane Glass; a *concavo*-convex Lens is represented by two spherical Glasses, that are Portions of different Spheres, and the Convexity of the Portion of the greater Sphere must be turn'd towards the inside of the Box.

Whilst the Light passes thro' these Boxes, the Changes of the Light are visible to the Eye in

 its

its Entrance into, and Emerſion out of a denſer Medium, and by the Aſſiſtance of theſe, all things relating to convex Lenſes are clearly demonſtrable.

Experiment 1.] *Ex gr.* Let P be one of the foremention'd Boxes, with the ſpherical Glaſſes V, V, the Convexities being placed outwards; let it be fill'd with Water; in a dark Room let a cylindric Beam of the Sun be horizontally reflected from the Looking-glaſs S; let this Beam enter the Box; the parallel Rays, of which it is form'd, will be inflected towards one another, and will converge; at their Emerſion on the other ſide they will converge more, and concur in F. Experiments may be made of the incident Rays, which diverge or converge, by uſing the Board with the convex Lens, as in the Experiments of the former Chapter.

Every Point of a lucid Body, as was ſaid be-
* 688 fore, is a radiant Point, * and being placed at a due diſtance from a convex Lens, every one has
* 698 its Focus. *

Experiment 2.] Let a lighted Candle be remov'd from a convex Lens beyond the Focus of parallel Rays; at the oppoſite Part of the Lens, upon a white Plane, by the Foci of the Points of the Flame, it will be repreſented; and this Repreſentation will be inverted, by reaſon of the Interſection of the Rays in their Paſſage thro' the Glaſs.

703 *Convex Lenſes are alſo burning Glaſſes,* becauſe
* 698 they collect the Rays of * the Sun, which, upon the account of the immenſe Diſtance of the Sun, are eſteem'd as parallel; but Rays united in a Focus (by reaſon that the Fire, that was before diſperſed, is now collected, and by rea-

ſon

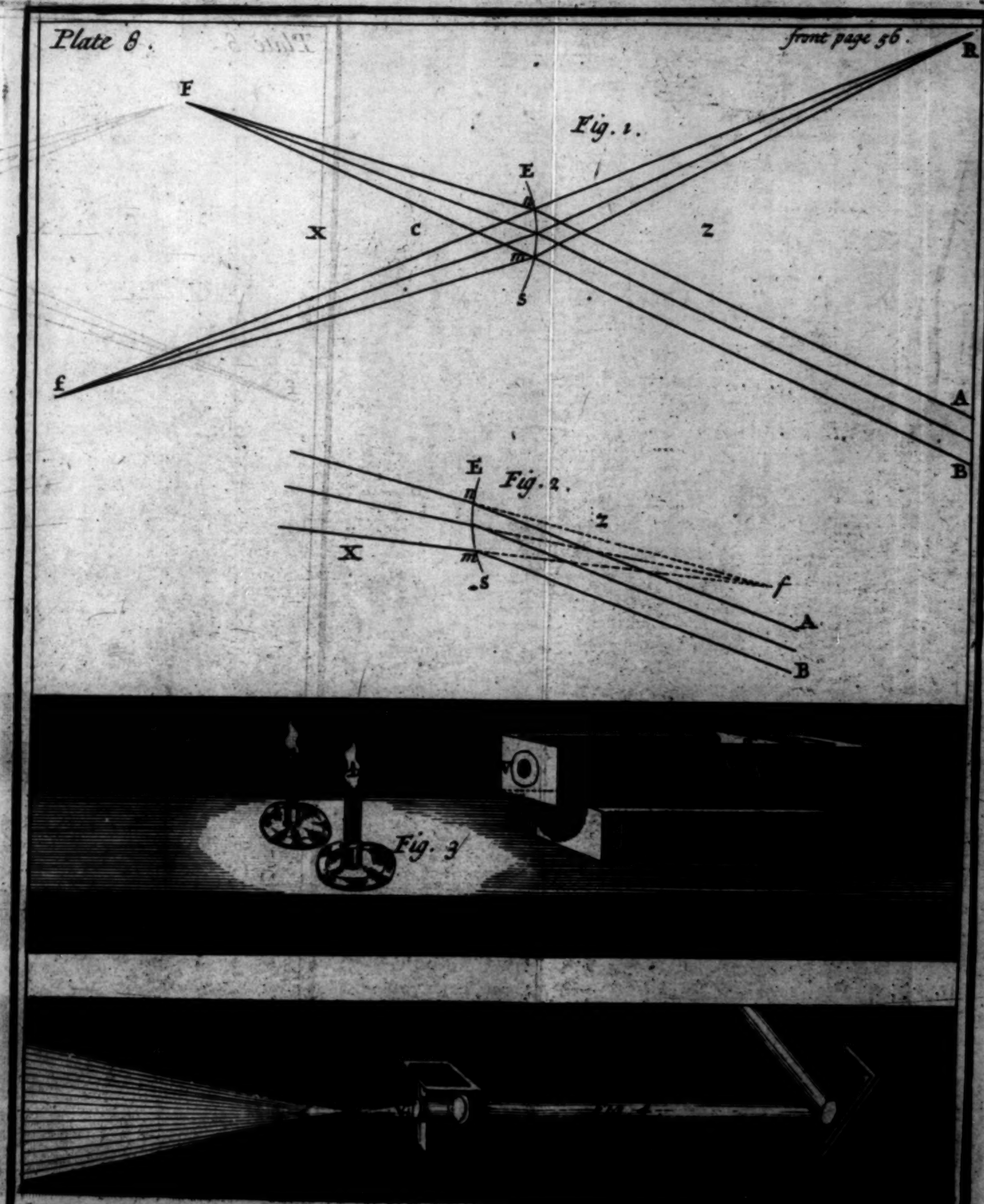


Plate 8.
front page 56.
Fig. 1.
F
E
n
m
S
X
C
Z
f
R
A
B
Fig. 2.
E
n
m
S
X
Z
f
A
B
Fig. 3

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ſon of the Motion of the Fire according to various Directions) do burn vehemently.

Experiment 3.] Take a convex Lens of any Magnitude, let it be ſo expoſed to the Rays of the Sun, that the Axis of the Lens may be in the Direction of the Rays; if any combuſtible Body be placed in the Focus of the Sun's Rays, it will burn.

When, by reaſon of the Magnitude of the Lens, the Rays are not exactly enough collected, before they come to the Focus, they muſt be tranſmitted thro' another convex Lens that is leſs, by which they will be reduc'd into a ſmaller Compaſs, ſo as to burn more violently.

As for concave Lenſes, and their Properties, they may be eaſily deduc'd from * what has been ſaid. * 696

Parallel Rays become diverging, by paſſing thro' a concave Lens. 704

Diverging Rays diverge the more. 705

Converging Rays either converge the leſs, or become parallel, or (as it happens in ſuch as converge leſs) *go out from the Lens diverging.* 706

All which things happen to oblique as well as direct Rays, but more ſenſibly in the firſt. * 707 * 697

Plate IX. *Fig.* 1.] Boxes, to repreſent the Effects of concave Lenſes, are made in the ſame manner as thoſe that repreſent the Effects of convex ones,* the difference is only in the Poſition of the Glaſſes; in the firſt Box the Concavities of the two ſpherical Glaſſes V, V, are outwards; in the ſecond, inſtead of one of thoſe Glaſſes, you have a plane Glaſs; in the third you have two ſpherical Glaſſes, but Sections of different Spheres; the Section of the greater Sphere has its Convexity outwards, and the other its Convexity inwards. 708 * 702

Expe-

Experiment 4.] Parallel Rays of the Sun, reflected horizontally in a dark Chamber by the Looking-glaſs S, muſt be tranſmitted thro' the Box P, which is full of Water, and repreſents a Lens concave on both ſides; as they go into the Box they will begin to diverge, and as they go out they will diverge more.

The remaining Experiments, relating to concave Lenſes, are made in the ſame manner as has been ſaid in reſpect of convex Lenſes.

CHAP. X.

Of Viſion; where we ſhall ſpeak of the Make of the Eye.

THE Properties and Laws of the Refraction of Light, that we have explain'd, are of wonderful Uſe in repreſenting Objects to our Mind.

By theſe Laws, the Objects are beautifully painted in their proper Colours in the bottom of the Eye; and this Picture, as I ſhall ſay hereaf-
* 716 ter, * is the occaſion of the Ideas which are excited in our Minds concerning the Things that we ſee.

How this Picture is form'd in the Eye, cannot be explain'd, without examining a new Property of Light; namely, its Diviſibility, which is paſt our Comprehenſion.

DEFINITION.

709 *A Body that is not lucid, and intercepts the Light, is ſaid to be* opake.

710 *Several* among all the opake *Bodies*, when exactly poliſh'd (except perfectly black Bodies, if

there

there are any ſuch) have the Property of dividing Light, for they *reflect the Light, ſo that the Rays from every Point* being ſtruck back, are divided, and *recede every way,* ſo that *all the ſingle Points of the Body become as it were radiant Points,* from which Light goes every way.

Whence we deduce a Method of painting Objects upon a white Plane; for all the Points of the enlighten'd Body, from which the Rays come upon a convex Lens, have their Focus of the other ſide of the Lens.* The Foci of diſtant Objects, tho' not exactly, are ſenſibly at the ſame diſtance from the Lens; thoſe Objects may by theſe Foci be repreſented in the ſame Place; which Repreſentation is inverted, (by reaſon of the Interſection of the Rays as they go thro' the Glaſs) and ſenſible in a dark Place, in which Light comes in no way but thro' the Lens, and only that Light by which the Objects are repreſented. 711 * 699

This will do wherever the Lens is placed, and in reſpect of all the Points of Objects, enlighten'd by Rays of Light, from which right Lines without Interruption may be drawn to the Lens; in this manner the above-mention'd Diviſibility in Light may be proved, and the Aptneſs that Bodies, that reflect Light, have to divide it.

Experiment 1. *Plate* IX. *Fig.* 2.] Make an Hole in a dark Place, over-againſt ſeveral Objects that are at leaſt 50 Foot off or farther; let the Hole be V, and let it have a convex Lens in it that collects parallel Rays at the diſtance of about four or five Feet; if a white Plane be placed behind the Lens a little farther from it than that diſtance, all the Objects above-mention'd will be painted upon it in very beautiful Colours. It is to be obſerv'd, that the Lens muſt be placed in a Poſi-

tion parallel to the Plane; and that by moving the Lens or the Plane, the diſtance muſt be found at which the Objects are repreſented moſt exactly.

This Repreſentation of Objects has great Affinity with that by which the Objects that we ſee are repreſented in the bottom of the Eye, as will appear from the Make of the Eye.

712 The Figure of the Eye, when taken out of the Head, is nearly ſpherical; only the fore-part is ſomething more convex than the reſt.

The Section of the Eye is repreſented *Plate* IX. *Fig.* 3.

The Part A A, which is moſt convex, is tranſparent, and call'd the *Tunica Cornea*.

The whole Covering of the Eye, except the *Cornea*, is call'd the *Sclerotica*, B A A B.

That Part of the *Sclerotica* which is next to the *Cornea*, is call'd the *Adnata*, or *White of the Eye*.

Behind the *Cornea*, on the inſide, is a Coat call'd the *Uvea*, which has in its middle an Hole *p p*, call'd the *Pupil*.

The Uvea is made up of concentric circular Fibres, interſected at right Angles by ſtrait Fibres; if the firſt are ſwell'd, the laſt are relax'd, and the Pupil is leſſen'd or contracted; and a contrary Motion of the Fibres increaſes or widens it.

In the middle of the Eye, but nearer the fore-part, there is a tranſparent ſoft Body C C, like a convex Lens, whoſe hind-part is more convex than the fore-part; it is call'd the *Cryſtalline Humour*; its Axis coincides with the Axis of the Eye, that goes thro' the Centers of the Pupil and the whole Eye.

This cryſtalline Humour is ſuſtain'd by ſmall Fibres or Threads, which are fix'd to all the Points of its Circumference, and likewiſe to the

inſide

inside of the Eye; they are inflected in the Form of an Arc, and every one of them is a Muscle; they are call'd the *Ligamenta Ciliaria*, and two of them are represented by *l* C, *l* C; they all cohere to one another, and together with the Crystalline, make a Separation in the Eye, and divide it into two Cavities, one forwards *p p*, and the other backwards S S.

The Cavity that is forwards is fill'd with a Liquor like Water, call'd the *aqueous Humour*.

The hind Cavity is fill'd with a transparent Humour, nearly of the same Density as the aqueous Humour, but not so fluid, call'd the *vitreous Humour*.

The hind Surface of the Eye within is lin'd with a Coat call'd the *Choroides*, which is again cover'd with a thin Membrane call'd the *Retina*.

At the back Part of the Bulb of the Eye, a little on one side, is the optic Nerve N N, so join'd to the Eye, that the Eye itself is as it were an Expansion of the optic Nerve, for the expanded Coats of the Nerve form the *Choroides* and *Sclerotica*, and the Fibres, which make up the *Retina*, concurring, make the Marrow of the Nerve.

The Eye is mov'd in the Head by several Muscles inserted in the *Sclerotica*, but we shall not treat of them here; as we only consider the Eye with respect to the Motion of Light, we purposely forbear to take notice of any thing else.

Rays that proceed from any Point, and enter the 731
Eye thro' the Pupil, go out of a rarer into a denser Medium thro' a spherical Surface; and therefore *if that Point be at a due distance from the Eye*, the Rays *after Refraction will converge*; * in the same • 661
manner as in the Experiment of N°. 663. (*Plate* VI. *Fig.* 4.) in which the Glass V represents the transparent *Cornea* of the Eye, whilst the Water in

in the Trough is instead of the aqueous Humour; and therefore, *supposing only the Cornea and the*
714 *aqueous Humour, there will be in the Eye an inverted*
*710, *Picture of the Objects.* *
711

Experiment 2. *Plate* IX. *Fig.* 4.] Let P be the Trough above-mention'd full of Water, and set in a dark Place, which has an Hole about half an Inch wide, so disposed towards enlighten'd Objects at a certain distance, that one may see them through the Hole; let the Glass V of the Trough be applied to this Hole, and upon the white Plane T you will have an inverted Picture of the Objects; by moving the Plane backwards and forwards, you will find the Place where the Picture is most distinct.

If the above-mention'd Picture, which we have imitated in this Experiment, was to be made in the Eye, it would be at too great a distance from the *Cornea*, and beyond the bottom of the Eye; and therefore this distance is diminish'd *by help of*
715 *the crystalline Humour*, which is denser, but encompass'd with rarer Mediums; for the Rays converging in the aqueous Humour, pass thro' the crystalline into the vitreous Humour; that is, out of a rare Medium thro' a denser (which is terminated by two spherical convex Surfaces) into a rare Medium again; by which Motion the
* 700 Rays converge still more; * and therefore they concur sooner, and *the Picture above-mention'd falls within the Eye.*

716 *The Objects which*, as we have explain'd, *are represented in the bottom of the Eye, are painted upon the Retina; and by the Motion of Light the small Fibres, of which the Retina is made up, are agitated; by which Agitation, the* Ideas *of the Objects painted in the Eye, are excited in the Mind.* The Connexion between the *Ideas* and the Motions by which they

they are excited, is unknown to us, * as we ſaid before: In determining the Cauſes of Senſations, we can go no farther than the Agitation of the Nerves. * 502

The more exact the Picture above deſcribed is, the more diſtinct will the Objects appear. 717
When the Rays coming from the ſame Point are not exactly united upon the Retina, its Picture is not a Point, but a Spot, which is confounded with the Pictures of the neighbouring Points; in which Caſe the *Viſion is confuſed.* 718

But when, *according to the different diſtance of the radiant Point*, its Focus is brought nearer, or remov'd farther off, * *it is neceſſary that there ſhould be a Change in the Eye, leſt* the Place, in which the Picture is exact, ſhould fall ſhort of, or beyond the Retina, and ſo *the Viſion ſhould be confuſed.* 719 * 663

But it is very difficult to determine what this Change is, and Philoſophers are divided in their Opinions about it; I ſhall only obſerve in general, that *it is not very probable that the Figure of the whole Eye is changed, in order to put back or bring forward the Retina*; and therefore we muſt expect to find this Change within the Eye. 720

For if the Figure of the Eye was chang'd, as this Change muſt be equally neceſſary in all Animals, the Eyes of all Animals would undergo the ſame Changes; for the ſame natural Effects cannot have different Cauſes. Now in the Whale the *Sclerotica* is too hard to be ſubject to any Alteration of Figure. Beſides, if there was ſuch a Change in the whole Eye, it would ariſe from the external Preſſure of the Muſcles, which would be different in different Poſitions of the Eye, and only regular in one Situation of it.

If now we examine the Eye within, it will appear neceſſary that there ſhould be a Change in the Cryſtalline, which by changing its Place or

Figure

Figure in the Eye, will produce the desired Effect; for the Rays that fall upon the *Retina*, before they are united, will be made to unite just upon the *Retina*, if the Crystalline becomes more
* 695 convex, * or if (its Figure remaining the same) it be brought forwards towards the *Cornea*.

721 That *the Position of the crystalline Humour is* easily *changed, and* that *it is brought nearer to, or farther from the Retina*, its Axis remaining the same, is plain, because the ciliary Ligaments are muscular; when these Muscles are swell'd, and become shorter, the Hollow which their Inflection makes at Cl, Cl, becomes less; by which means the vitreous Humour is compress'd, and therefore it presses upon the Crystalline, and pushes it forwards farther from the *Retina*; which is necessary when we look at near Ob-
* 663 jects. *
699 From an Experiment, that we shall hereafter
753 mention, it has been demonstrated, that there is another Change in the Eye that acts contrary to this; and we shall shew what is the occasion of it. The second Change is also to be referr'd to the
622 Crystalline; which *(when it is drawn by the ciliary Ligaments, to make it recede from the bottom of the Eye) becomes also flatter, and therefore it must recede farther than if its Figure was unchangeable*; that is, the Change becomes more
* 730 sensible; which we shall shew to be of Use. *

These Changes in the Eye have their Limits, for which reason also *Objects appear only distinct*
724 *within certain Limits, which are different Distances*
725 *according to the difference of Peoples Eyes; and very often in the same Man, both Eyes have not the same Limits*; which is almost of the same Use, as if the Limits of both Eyes were more distinct from one

one another: For one may ſee an Object diſtinctly enough with only one Eye. In ſome Perſons alſo the neareſt Limit of one Eye is farther off than the fartheſt of the other: In which Caſe near Objects and diſtant Objects are ſeen diſtinctly, but the intermediate ones appear confuſed.

The Picture in the Bottom of the Eye, as has 726
been ſaid, * is inverted; whence a Queſtion a- *714
riſes, why we ſee Objects erect? To which we anſwer, by asking another Queſtion; Whether it is more eaſy to conceive the Connexion between an Idea in the Mind, and an erect Figure, than an inverted one? We confeſs, that we have no Notion of that Connexion in either Caſe: But Experience teaches us, that there is a Connexion between an inverted Picture in the Eye, and the Idea of an erect Object; and further than this we do not know.

If we look at the ſame Object with both Eyes, 727
it will appear ſingle; but this happens only when the Object is painted in correſpondent Points of each Retina; which probably happens from the meeting of the Optic Nerves. For it is obſerved in all Animals, which ſee the ſame Object with both Eyes, that the Optic Nerves meet and ſeparate again before they go to the Brain; but in Animals which ſee different Objects with each Eye, the Optic Nerves go ſeparately from the Eyes to the Brain.

Only one Point at a Time can be ſeen diſtinctly, 728
namely, that which is repreſented in the Axis of the Eye; if we look at one Point with both Eyes, we muſt ſo direct the Eyes, that their Axes continued ſhall meet in that Point; which happens when we have our Eyes intent upon any Point.

By this Direction of the Axes we judge of the Distance of Objects; for the Situation of the Eyes alter according as the Axes make a different Angle, which Angle depends upon the Distance of the Object: Whence it happens, that without perceiving when we do it, by Use we get a Habit of judging of the Distance of

729 Objects *by the Direction of the Axes*; which is sensible to us, because it depends upon the Motion of the Eye, that we feel. Therefore we may see the Use of having two Eyes placed at a certain Distance from one another; *as long as this Distance of the Eyes bears a sensible Proportion to the Distance of the Objects, we can judge of it pretty certainly.*

730 *We can also judge of lesser Distances with one Eye alone*; because in the Variation of a small

721 723 Distance, the Change in the Eye is sensible.

731 *In great Distances*, if we look at known Objects, *we judge from the apparent Magnitude and the Colour.*

732 *It is impossible to judge of very great Distances, except the same Objects be seen from different Places.*

733 *The apparent Magnitude of an Object depends* upon the Bigness of the Picture in the Bottom of the Eye, which Picture depends *upon the Angle under which an Object is seen*, that is, the Angle which is form'd by Lines drawn from the Extremities of the Object to the Eye.

734 *This* apparent *Magnitude* is to be distinguish'd from the Magnitude *which our Mind attributes to the Object that we see*, which last is founded upon the Judgment, whose Foundation is not in the Appearance alone. Every Body knows that the Object appears the less according as it is more distant; whence it happens, that, *according to the greater Distance of the Object*, if it be known, the apparent Magnitude of the Object *is increas'd* in

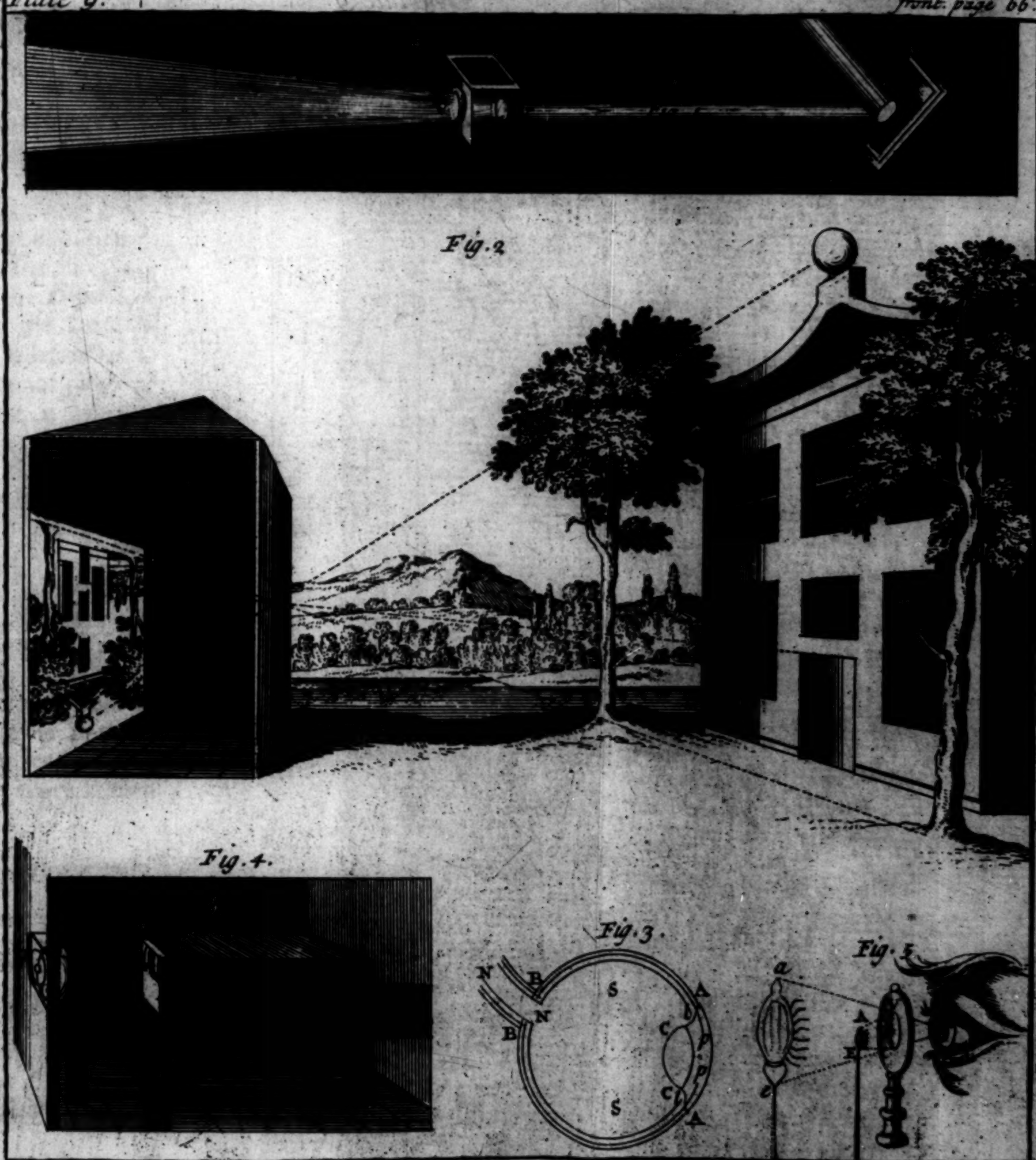
Fig. 2
Fig. 4.
Fig. 3
N
B
N
B
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Fig. 5
a
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E
e

in the Judgment that our Mind makes of it, which we do without any Attention to it. Therefore the same Object at the same Distance appears of a different Magnitude, if we judge differently of the Distance.

We have a remarkable Example of this in re- 735
spect of the Sun and Moon, which appear greater when near the Horizon, than at a greater Height; tho', as is known to Astronomers, the Picture of the Sun in the Bottom of the Eye is the same in both Cases, and that of the Moon is less when it appears nearer the Horizon; we cannot judge of the Distance in either Case, * but it appears *732
greater near the Horizon, by reason of the Interposition of the Fields and Part of the Heavens. If we see the Bodies above-mention'd thro' a Tube, this apparent Distance vanishes, as also the Magnitude which is deduced from it. From our Childhood upwards, and so continually, we join the Idea of Distance with the Increase of apparent Magnitude, (which is necessary for making a true Judgment concerning the Magnitude) whereby the Ideas are so closely join'd, that they cannot be separated, not even in those Cases, in which we know that they lead us into Error. Logicians teach us, how many Errors are to be attributed to Ideas so join'd.

CHAP. XI.

Of Vision thro' Glasses, and how to correct some Defect of the Eyes.

AN Object is visible, because all its Points 736
are as it were radiant Points; * therefore *713
a *Point appears in that Place from whence diverging* 714
Rays are emitted. 715

737 *If Rays inflected any how enter the Eye ...verging, the visible Point will be in the imaginary Focus of the Rays*; for the Rays enter the Eye exactly in the same Manner that Rays would do that came directly from that Focus; and to have them unite upon the Retina, the same Situation of the Crystalline is requisite; so that, in respect to a Spectator, it is no Matter whether those Rays, after Refraction, or these directly enter the Eye; and there will be the same Motion in the Eye, when
719, 730 it fits itself for distinct Visions.

738 *A Point appears the more enlightened, the greater Number of Rays coming from it enter the Eye.*

739 *When Objects are seen thro' a plain Glass terminated with parallel Surfaces, they appear to be nearer than when seen with the naked Eye.* Let A (*Plate* X: *Fig.* 1.) be a visible Point; the Rays, going from it and entering the Eye, are between A *b* and A *b*; these, being refracted in the Glass V V, move along *b c*, *b c*, and go out thro' *c d*, *c d*,
*628 which are parallel to the Lines A *b*, A *b*: * now because *b c*, *b c*, are refracted towards the Perpen-
*624 dicular, * *c d*, *c d*, fall between *b* A and *b* A; that is, they intersect at *a*, which is nearer than A; therefore the imaginary Focus of the Rays which enter the Eye is at *a*, in which the Point A ap-
737 pears to be.

740 *That Point* also *appears to be more enlightened, when seen thro' the Glass above-mentioned.* For all the Rays between A *b* and A *b* enter the Pupil between *d* and *d*; but as the Lines A *b*, A *b*, are parallel to the Lines *c d*, *c d*, and these are between those, A *b* and A *b* being continued would fall beyond *d* and *d*; therefore if the Glass was taken away, the Rays, which now enter the Pupil, would take up a greater Space, and therefore would not all enter the Eye.

Plate

Plate X. *Fig.* 2.] *The apparent Magnitude of an Object is increased by the Interposition of a plane Glass*; the Object A E is seen by the naked Eye under the Angle A *d* E; but if you use the Glass V V, by reason of the Refraction thro' A *b c d* and E *b c d*, it will be seen under the Angle *c d c*, which is greater than the last. *But yet the Object is not greater in Proportion to the increased apparent Magnitude*; * for it appears to be at a less Distance.* 741 742 *734 *739

The Increase of apparent Magnitude is so much the greater, as is the Difference of the Angles A *d* E and *c d c*; whose Difference *increases* as the Intersections of the Lines A *d* with *b c*, and E *d* with *b c*, come nearer to the Points *b* and *b*; which obtains *as the Object is brought* nearer to the Glass; and therefore it is the greatest of all, when the Object touches the Glass; which shews that Objects, even in the Glass itself, must appear magnified. 743

And in general, *the Eye being placed in a rarer Medium, the Object that is seen in a denser Medium appears bigger, and is also brought nearer by the Refraction.** This is every Day confirm'd by Experience, when we look at Objects in the Water. 744 *659

Let there be *a Point* A *seen thro' a convex Lens* V V, (*Plate* X. *Fig.* 3.) and the Rays A *b*, A *b*, at *c d*, *c d*, will go out more diverging, as if they came from *a*; * therefore that Point *appears to be at a greater Distance.** *It appears also more enlightened*; for the Rays come nearer to each other as they go thro' the Glass, * and are also reduced into a less Space, wherefore a greater Number of them must enter the Pupil. 745 *699 *737 746 *695

The apparent Magnitude of an Object is also increased; that is, the *Object seen thro' a convex Glass* is seen under a great Angle, which ap- 747

pears from a Sight of the Figure; the Object
A E, seen with the naked Eye, is seen under the
Angle A *d* E, (*Plate* X. *Fig.* 4, and 5.) but now
it is seen under the Angle *c d c*, which is greater;
(in *Fig.* 4.) the Rays A *b*, E *b*, which are con-
vergent, converge more as they go out of the
*700 Lens; * or diverging (as in *Fig.* 5.) they come
699 to the Eye converging. Therefore the Object
appears magnified, both from the Appearance of
*745 it being farther, * and its Magnitude being in-
*734 creas'd; * and therefore *the Magnitude, that we*
748 *attribute to an Object, does not follow the same Pro-
portion as the apparent Magnitude*; for which Rea-
son we shall not delay Time in Demonstrations
about it: But we shall observe in general,

749 That *the Angle, under which an Object is seen
thro' a convex Glass, diminishes as the Eye recedes
from the Glass; whilst the Object is not more distant
from the Glass than the Point in which parallel Rays
are collected: But if the Object is farther off, the
apparent Magnitude is increased as the Eye recedes.*

750 After the same Manner, *if the Eye be between
the Glass and the Focus of parallel Rays, the Angle
above-mention'd is diminished as the Object is farther
removed; the Eye being placed at a greater Distance,
the same Angle is increased as the Object is farther
removed*; in which last Case the Object may be
so far removed, as not to be visible beyond the
754 Glass, as will be said anon.

Also in those Cases in which Objects are vi-
sible, they do not always appear distinctly.

751 For, *that a Point may appear distinct, it is re-
quired that the Rays that proceed from a Point should*
*736 *enter the Eye diverging, * and that the imaginary*
727 *Focus of those Rays, in respect of the Spectator,*
724 *should be within the Limits of distinct Vision.**

752 If the Object be removed beyond the Focus
of parallel Rays, the Rays flowing from a Point
of

of the Object, enter the Eye converging; * which *699
Case is impossible to the naked Eye: In this the Vision is always confused, and the Eye disposes itself so as to have the Vision the least confused that may be; from this Disposition we judge of the Distance, as we do in every Case in which
we judge of it with only one Eye.* *730

753 But this Distance does not always appear to be the same; whence may be deduced what is said of the Change of the Figure of the Crystal-
line.* For if, supposing the Crystalline moveable, *722
its Figure be unchangeable, in every Situation of the Object and the Eye, in which the Rays, coming converging from a Point, enter the Eye, there will be the least Confusion, if the Crystalline comes back towards the Retina as far as may be; so that in every Case there would be the same Disposition of the Eye, and the same Judgment concerning the Distance; which, as has been said, is contrary to Experience: But if it becomes flatter as it recedes from the Retina, there will be Changes in the Eye, which agree with the several Judgments made of the Distance in different Situations of the Object and the Eye.

754 *If in the last Case, in which Rays, coming from a Point converge, the Eye be so removed, that the Rays unite before they come to the Eye*, in all the Points in which the Rays concur, there will be radiant Points; which are the Foci of all the Points of the Object, by which the Object is represented
inverted upon a white Plane; * and which are *711
visible Points in respect of the Eye, to which
the Rays can come after their Interfection.* In *736
that Case *the Object appears inverted*, because we don't see the Object itself but its Representation behind the Glass, which we have said to
be inverted.* *711

 We

755 We have ſaid that the Caſe is impoſſible to the naked Eye, in which the Rays, coming from a Point, enter the Eye converging; and therefore ſuch Viſion is always confuſed, becauſe the Conſtruction of the Eye cannot adapt itſelf to an impoſſible Caſe: Yet ſometimes, but rarely, even in that Caſe, the Objects are ſeen diſtinctly; which, as it is occaſioned by ſuch a Defect of the Eye as takes away all diſtinct Viſion from the naked Eye, I did not think proper to take Notice of ſuch Exceptions of the general Rule.

756 *The Fault of the Eyes of a great many old Men* is, that they can ſee none but diſtant Objects diſtinctly, thoſe that are near appearing confuſed to them; which Defect *is corrected by the Interpoſition of a convex Lens.* The Rays, which flow from a Point which is near, concur beyond the Retina; paſſing thro' a convex Glaſs, they will diverge leſs as they enter the Eye, and ſo concur ſooner in the Eye; that is, come to the Eye as if they flowed from a remote Point, ſuch as is ſeen diſtinctly by an old Man.

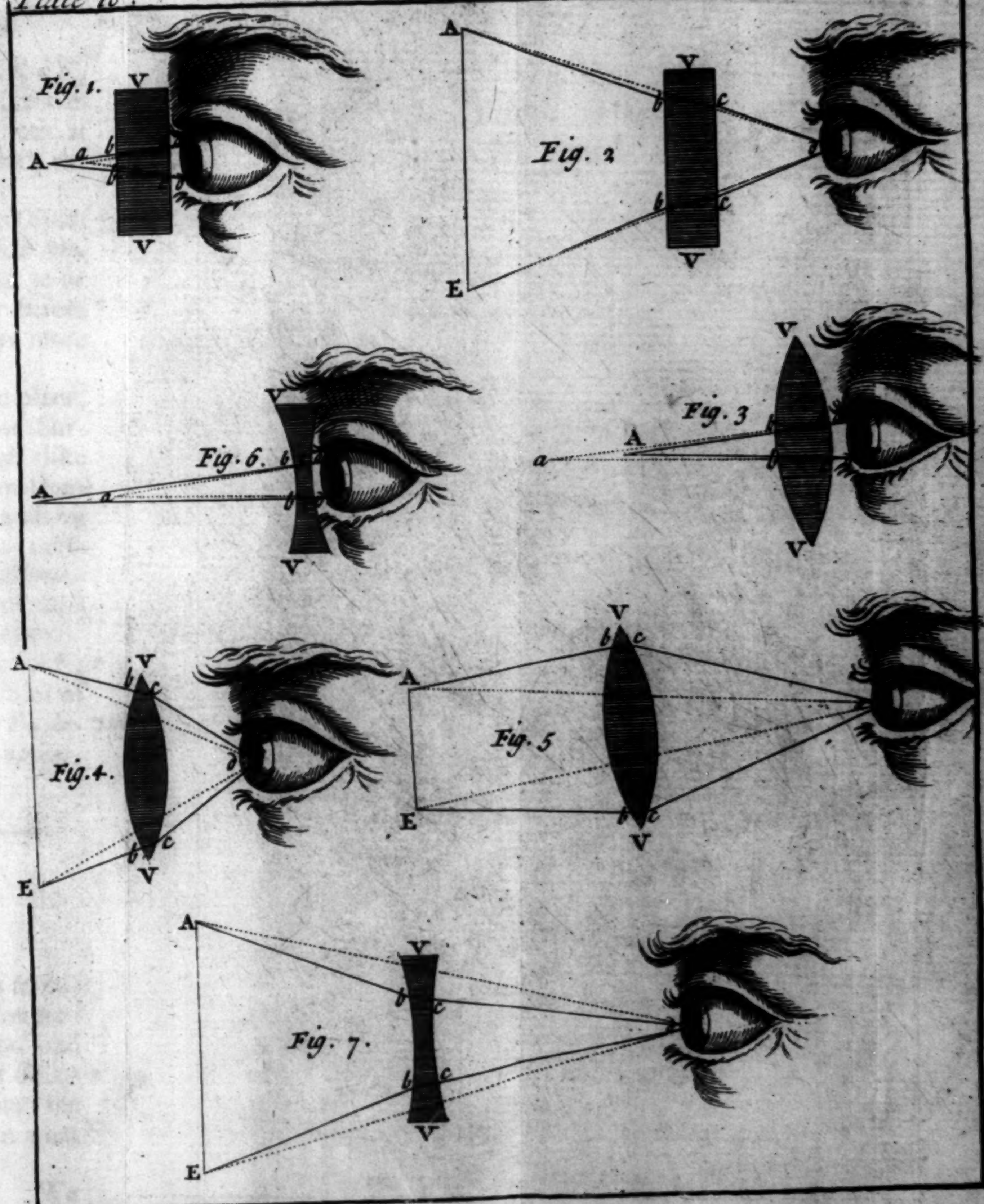
757 *Thro' a concave Lens, Objects appear to be nearer, leſs enlighten'd, and leſs.*

Plate X. *Fig.* 6.] The Rays A *b*, A *b*, and all that are between, going thro' a concave Lens
*705 become more diverging, * and enter the Eye as
*652 if they came from a Point *a*, which is leſs diſtant,*
737 where the Point A appears to be.

By making the Rays to diverge more, they are carried farther aſunder; and therefore fewer of them enter the Eye, which diminiſhes the
738 Illumination of the Point ſeen.

Plate X. *Fig.* 7.] The apparent Magnitude is alſo diminiſh'd, becauſe the Rays A *b*, E *b*, by which we ſee the Extremities of the Object,
*706 come to the Eye leſs converging, * and therefore the Angle *c d c*, under which the Object is ſeen beyond

Plate 10. front page 72.



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beyond the Lens, is less than the Angle A d E, under which it is seen by the naked Eye; therefore upon account of the Diminution, both of the Distance and the Angle above-mention'd, the Object appears diminish'd.* * 734

758 *A concave Lens is of use to those who see no Objects distinctly but such as are near,* such are call'd *Myopes*; thro' this Lens remote Points appear to be near, * and the Rays, which did concur before * 757 they came to the *Retina*, now enter the Eye more diverging, and meet upon the *Retina*.

There are Glasses that have one Surface plane, and the other side is made of several plane Surfaces, that make Angles one with another (like a Diamond) thro' these the Rays that flow from one Point suffer different Refractions, and by every Surface are made to enter the Eye in a different Direction, as if they came from different Points; that is, the same Point forms several imaginary Foci, and therefore appears multiplied, for it is seen in several imaginary Foci*; * 737 which, as it happens in respect of every Point of the Object, *thro'* such *a Lens, which is a Polyhedron* (or multiplying Glass) *the Object appears multiplied.* 759

CHAP. XII.

Of Microscopes and Telescopes.

WE have shewn of what Use Glasses terminated with spherical Surfaces are for correcting the Defects of the Eyes of Old Men, and of the short-sighted*; how they serve for disco- * 756 vering the smallest Objects, and bringing the 758 most distant (as it were) to the very Eye, is what we are now to consider.

We

We have ſaid that the convex Glaſſes magnify
* 747 the Objects*, which magnifying depends upon the Refraction of the Rays as they go thro' a convex Lens; whence it follows, that it is increaſed, if in the ſame Circumſtances the Refraction be increaſed; which Effect may be produc'd, by augmenting the Convexity of the Lens, which will be the more convex, as the Surfaces that terminate it are Segments of a leſs Sphere, which can only be had in very ſmall Glaſſes.

Definition I.

760 Such ſmall Lenſes are call'd *Microſcopes.*

761 *By a Microſcope ſmall Objects are vaſtly magnified,* by which means, things which would be inviſible to the naked Eye, are very diſtinctly ſeen.

Definition II.

762 *The Space ſeen thro' the Microſcope, that is, the Circle in which Objects are viſible thro' the Microſcope, is called the* Field of the Microſcope.

Experiment 1. *Plate* IX. *Fig.* 5.] If we look at the ſmall Object A E thro' the Microſcope V,
* 745 it will appear magnified at *a e**.

747 There are alſo compounded Microſcopes, made up of two or three Lenſes; what Foundation they depend upon, will be ſufficiently ſhewn by explaining one of thoſe which is made up of two Lenſes.

Plate XI. *Fig.* 2.] Take a ſmall Lens that is very convex, as V V, and let the Object A E be plac'd at ſuch a diſtance from it, that all its
* 710 Points ſhall have their Force beyond the Lens*;
699 let the Object be brought ſo near, that the Foci
* 699 may be remov'd to *a e**, and you will there have the Repreſentation of the Object very much enlarg'd,

larg'd, which will be ſenſible if you receive it there upon a white Plane*. * 711

Experiment 2. *Plate* XI. *Fig.* 1.] The Lens above-mention'd muſt be made faſt in the End of a Tube at V; and the other End of the Tube, which is wider, muſt be cover'd with a very thin Paper C C; the Object A E muſt be ſo plac'd, that the Foci of the Points of that Object ſhall be juſt at the diſtance of the Paper; if then the Object be well enlighten'd, you will have its Repreſentation inverted, viſible thro' the Paper at *a e*. By moving the Object, you will have the true Poſition that brings the Repreſentation upon the Paper to be diſtinct.

Plate XI. *Fig.* 2.] All the Points of the Repreſentation *a e* are radiant Points, and therefore viſible*, which being ſeen thro' a large Micro- * 736
ſcope V V, ſhews the large Repreſentation *a e* 754
at a e*; that is, the Rays coming from the Ob- * 761
ject A E, after the Refractions thro' both the Lenſes V V, V V, will enter the Eye, as if they came from an Object at *a e*.

Therefore *thro'* ſuch *a compounded Microſcope* 763
the Object appears inverted, and much more magnified than thro' a ſingle Microſcope.

Definition III, and IV.

In this Microſcope the ſmalleſt Lens, which is next 764
to one Object, is called the Object-Glaſs, *and the other the* Eye-Glaſs.

This laſt ought not to be too ſmall; for the Points of the Repreſentation *a b*, tho' they be radiant Points, do not emit Light every way; only the Rays which paſs thro' the Object-Glaſs interſect one another in the ſeveral Points of the Repreſentation *a b*; which Repreſentation therefore will not be viſible, unleſs the Rays that go thro' the Object-Glaſs do alſo go thro' the Eye-Glaſs.

765 Glaſs. *The Field* therefore (or the Space that the Microſcope can take in) *depends upon the Magnitude of this Lens.*

The Eye alſo muſt be ſo plac'd, that all the Rays that come to the Eye-Glaſs, going thro' it, ſhall come to the Eye; which is done by placing

766 the Eye at *d, the Point in which all the Rays which come from the Center of the Object-Glaſs, and paſs thro' the Eye-Glaſs, are collected.*

Objects appear bright enough thro' Microſcopes, becauſe they are very near the Glaſs, and ſo the ſame Number of Rays paſs thro' a ſmall Lens as would not paſs at a greater diſtance, unleſs thro' a great Hole; *yet often, where Objects are the moſt magnified, they muſt be enlighten'd by*

767 *Rays collected thro' a convex Lens and thrown upon them.*

The aſtronomical Teleſcope much reſembles the compound Microſcope.

Definition III.

768 *Inſtruments fitted to ſee diſtinct Objects, are called* Teleſcopes.

769 That which we now treat of is call'd the *aſtronomical* Teleſcope, becauſe it is not ſo fit for ſeeing Objects upon Earth, for it repreſents them inverted; but Aſtronomers do not much regard the Poſition of the Appearance of the Object.

This Teleſcope conſiſts of two convex Lenſes, the one an Object-Glaſs, which is plac'd next to the Object, and the other an Eye-Glaſs, plac'd next to the Eye; by help of the firſt, diſtant Objects are repreſented at a certain diſtance be-

* 711 hind the Lens*, as near Objects are in the compound Microſcope. If this Repreſentation be obſerv'd thro' an Eye-Glaſs, it will appear enlarg'd and inverted, as we have ſaid concerning the Microſcope.

It

It is plain alſo, that in this Caſe, as well as in the Microſcope, the *Field depends upon the Breadth of the Eye-Glaſs*; as alſo, that *the Place of the Eye must be determined in the ſame manner for the Teleſcope as for the Microſcope** ; for the aſtronomic Teleſcope differs from the compounded Microſcope only in this, that in the Microſcope the Lenſes are more convex, and therefore leſs proper for looking at diſtant Objects, eſpecially in reſpect of Object-Glaſſes. In the Microſcope the Object-Glaſs is more convex than the Eye-Glaſs; but the contrary obtains in the Teleſcope. 770 771 * 766

Teleſcopes cannot be too long for obſerving the Stars; but if they are above 20 Foot long, they are of no uſe for ſeeing Objects upon Earth, becauſe of the conſtant trembling of the Air, which is too ſenſible in Glaſſes that magnify very much.

772 A ſhort *aſtronomic Teleſcope will ſerve to ſee Objects upon Earth, by adding to it two convex Lenſes*, which are alſo call'd Eye-Glaſſes; the three Eye-Glaſſes are alike, and leſs convex than in the aſtronomic Teleſcope, the Object-Glaſs remaining the ſame.

773 *Plate* XI. *Fig.* 3.] Take an Object-Glaſs V V, which repreſents a diſtant Object at *e a*; then take beſides three Eye-Glaſſes D D, D D, D D; the firſt muſt be ſo plac'd, that the Rays coming from the Point of the Repreſentation *e a*, ſhall become parallel when they have paſs'd the Lens*; in that Caſe the Rays which come from the middle Point of the Object-Glaſs, will be collected at G; the ſecond Lens muſt be ſo plac'd, that theſe Rays which are collected at G (where they interſect one another, and move as if they came from that Point) may go out parallel after they have paſs'd thro' it*; which being perform'd, the Rays coming from the Object-Glaſs to *e*, and * 699 * 669

there interſecting and forming that Point of the Repreſentation of the Object, being refracted thro' the firſt Lens, paſs by G parallel to one another; thro' the ſecond Lens they are refracted in the Direction D e, and collected at e*, ſo as to make it the Point of a new Repreſentation. In the ſame manner the Point of a new Repreſentation correſponds to the Point a of the ſecond Repreſentation; which being alſo true concerning the intermediate Points, there will be found an erect Repreſentation of the Object at a e.

* 698

Experiment 3. *Plate* XI. *Fig.* 4.] Let three little Boards D, D, D, with Eye-Glaſſes in them, that collect parallel Rays at the diſtance of about five Inches, be moveable upon a Plane between two Rulers, in ſuch manner that the three Glaſſes may be in the ſame Line as the Hole V, thro' which alone the Light enters into the Room, and in which there is an Object-Glaſs, which is fix'd in a ſhort Tube, in order to exclude all the ſide Light.

This Object Lens is ſuch, as is able at the diſtance of three Feet from V, to repreſent diſtant Objects inverted at F; which Repreſentation will be viſible, if you let the Rays fall upon a white Plane in that Place*. Five Inches farther from F you muſt place the firſt Eye-Glaſs, and ten Inches from that you muſt place the ſecond; at *f*, which is five Inches from it, you will have an erect Repreſentation of the ſame Objects, which will alſo be viſible, if receiv'd upon a white Plane.

* 711

774 *Plate* XI. *Fig.* 3.] If the Repreſentation a e be ſeen thro' a third Eye-Glaſs, ſuppoſing the Eye at *o*, in which the parallel Rays a D and a E are collected, *the Object appears magnified, brought near, and erect*; for it is ſeen under the Angle

D *o* D,

D o D, when with the naked Eye it would appear under a very ſmall Angle; it will alſo appear near, becauſe, tho' it be ſeen beyond a e, yet the diſtance at which it appears has no ſenſible relation to the diſtance of a very diſtant Object.

Experiment 4. *Plate* XI. *Fig.* 4.] Suppoſing every thing as in the foregoing Experiment, let there be a third Eye-Glaſs plac'd ten Inches from the ſecond, and 5 Inches from that a little Board, or Eye-Stop, with an Hole O; if the Eye be placed at O, the Object, as has been ſaid, will appear erect, magnified, and near. If the Board O be diſplac'd, that is, be brought nearer, or removed farther off, the Field of the Teleſcope is diminiſh'd; becauſe there is but one Situation of the Eye, in which all the Rays which paſs thro' the Eye-Glaſſes can come to the Eye.

We are to take notice, that the Eye-Glaſſes made uſe of here, are not convex enough in reſpect of the Object-Glaſs V; but they are beſt for making the third Experiment.

All the Points of the Object do alſo *appear more* 775
enlighten'd; for the Rays which, coming from any Point of the ſeveral Points of the Object-Glaſs, do interſect one another in a Point of the Repreſentation, by reaſon of the ſmall diſtance of the Eye-Glaſs from that Repreſentation, are but little diſpers'd before they come to the Eye; ſo that they all go into it: and therefore the Illumination given by the Teleſcope, is to that which is given by the naked Eye, as the Surface of the Object-Glaſs, thro' which the Rays paſs, to the Surface of the Pupil. * * 738

One may alſo *with two Lenſes make Teleſcopes,* 776
which ſhall ſhew Objects erect, enlighten'd, and magnified; theſe muſt be ſhorter, for if they be above a Foot long, they become almoſt uſeleſs, becauſe

because their Field will be so small; that is, they will take in so little of an Object.

Plate XI. *Fig.* 5.] Let V V be an Object-glass, the inverted Representation of a distant Object
* 711 will be at *e a* *; the Rays are so intercepted by the concave Lens D D, that such of them as come from the Center of the Lens V V, are inflected
* 705 as if they proceeded from the Point *f* *; by the same Refraction in the Rays which concurr'd at
* 706 *a*, become diverging *, having their imaginary Focus at a; which also happens in respect to all the Points of the Representation *e a*, and instead of it, you have an imaginary Representation which is erect at a e; that is, the Rays enter the Eye as if they came from the Object plac'd at a e.

777 The Rays in all respects go out diverging from the Eye-Glass, and therefore *the Eye must be brought as near as possible to the Eye-Glass.*

778 *In this Telescope the Field depends upon the Bigness of the Object-glass*; for the Rays, which from a Point come obliquely to the Center of this Lens, very often do not enter the Eye; whilst other Rays from the same Point, which pass thro' the Lens near its Circumference, do come to the Eye.

CHAP. XIII.

Of the Reflexion of Light.

WE have shewn that Light is reflected from opake Bodies, and that every Point re-
* 710 flects it every way *; the occasion of this is the Inequality of the Surfaces, which are made up of an innumerable Quantity of small Planes, which in all sensible Points are directed every

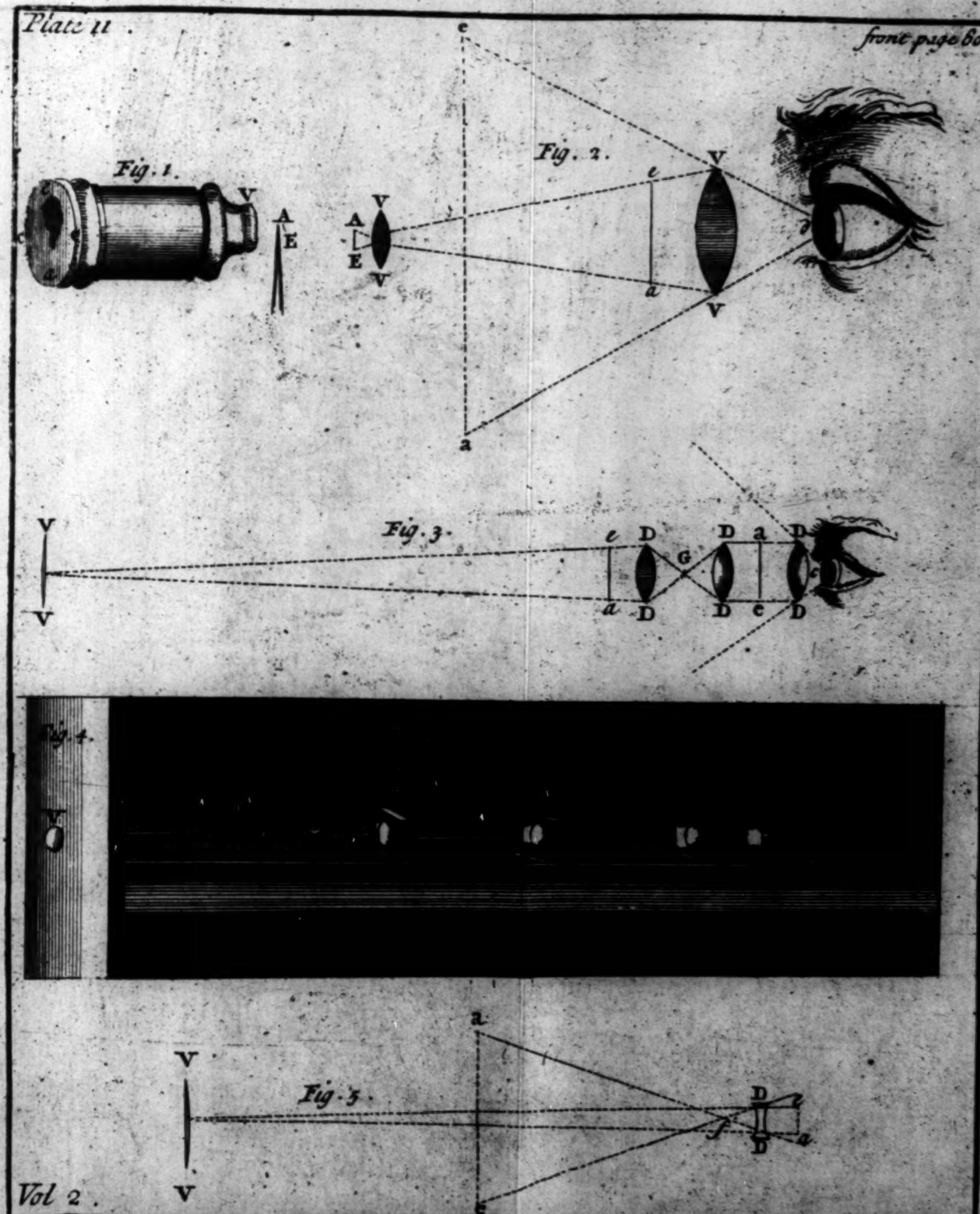
Plate 11.
front page 80.
Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
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every Way; which will be easily conceiv'd, if we imagine a Surface cover'd with an innumerable Quantity of small Hemispheres. That this is true, we deduce from the Reflexion of Light from a polish'd Surface; that is, from a Surface whose Inequalities are taken off; which 779
in all its Points reflects the Light only one Way, which holds in Curve as well as in plane Surfaces: Nay, from Surfaces that are not at all polish'd, the Light is mostly reflected that Way, and it would be all reflected if they were polish'd, as daily Experience shews.

Plate XII. *Fig.* 2.] Let A C be a Ray of Light coming obliquely upon a plane Surface; let C O be perpendicular to this Surface, and the Rays be reflected along C B.

Definition I.

The Ray C B is called the *reflected Ray.* 780

Definition II.

The Angle O C B is called the *Angle of Reflexion.* 781

The reflected Ray, together with the incident Ray, in the same Plane which is perpendicular to the reflecting Plane. 782

For *the Action of this Plane, by which the Light is reflected, is directed perpendicularly* to a Plane, which is supposed like in all Points. 783

The Angle of Reflexion is equal to the Angle of Incidence. 784

Experiment 1. *Plate* XII. *Fig.* 1.] Take a plane Looking-glass S, which may be set in any Position by Means of a Ball and Socket join'd to the Foot that sustains it; thro' a Hole, in the Plate of Metal L, that is in the Window, let in a Sun Beam of about a Quarter of an Inch Diame-

ter into the Room; the Glaſs muſt be ſo diſpoſed, that the Beam may come thro' an oblique cylindric Cavity (of the ſame Bigneſs as the Beam) made in a little upright Board T: If you turn this Board Side for Side, the reflected Ray will go thro' the ſame Cavity. This holds good, whatever the Inclination of the Cavity be, as may be demonſtrated by uſing different Boards.

By which Experiment N°. 779. is prov'd, as well as N°. 784.

785 *Plate* XII. *Fig.* 2.] *If the reflected Ray becomes the incident Ray*; that is, if the Light comes along the Line B C, it will return in the Line C A, that is, the firſt *that was the incident Ray will become the reflected Ray*; as appears from the Equality of the Angles BCO, OCA.

From this Equality of the Angles of Incidence and Reflexion, we farther deduce, that
786 *the Light, after it has fallen upon a Body, recedes from it with the ſame Force that it came upon it.* Let the Motion along A C be reſolv'd into two
*192 Motions along A O and O C *, ſuppoſing A O parallel to the reflecting Plane, and O C perpendicular to it. Let A O be continued; the Motion in that Direction is not alter'd from the Action of the Plane: Therefore let A O and O B be equal; if the Light recedes from the Plane with the ſame Force, with which it came upon it, the Motion occaſion'd by the Repulſion is repreſented by C O, and in that Caſe
*190 the reflected Ray goes thro' B *; that is, the Angle OCB is equal to the Angle OCA, which agrees with the Experiment.

787 As to the Reflexion of Light, it is to be obſerv'd, that *Light does not run againſt the ſolid Part of Bodies, when it is reflected by them; but that it is reflected in thoſe Places, where it could very freely paſs.*

I

pass. I shall prove this by several Experiments, by which many other wonderful Properties of Reflexion are discover'd.

It is a common Experiment observ'd by every 788
Body, that when Light is mov'd thro' any Medium, as for Example, Glass, Water or Air, it does not undergo a sensible and regular Reflexion; but that it is reflected there, where two Mediums of different Density are separated; so it is reflected in the Surface of Water or Glass.

Could Light in such Quantity strike against the Particles, just where the Mediums are separated, whereas it moves thro' both the Mediums for a great Space without striking against any such Particles; Are there more of those Particles near the Surface than elsewhere? *Light* also *is more* 789
abundantly reflected in a denser Medium, when it comes against the Surface of a rarer; than when on the contrary, moving in a rarer Medium, it strikes against the Surface of a denser.

Experiment 2. *Plate* XII. *Fig.* 3.] In a dark Place in which the Light enters thro' an Hole in the Plane L, let there be placed a triangular Prism of Glass AB; let the Light enter the Prism thro' one Side; if it comes to the next Side making an Angle of Incidence greater than 40 Degrees, it is wholly reflected, and does not at all penetrate into the Air; but Light moving in Air is never wholly reflected by the Glass.

But if the Reflexion be made by the striking of Light against the solid Parts of Bodies, there must be more such Parts in Air than in Glass; for if Light was reflected from the Glass itself into the Air, the Light would never come to the Separation of the Mediums; that the Light can also go out of Glass in the very Places, where it is reflected, is prov'd by following Ex-

 periments.

periments. Therefore in the Neighbourhood of the Glaſs there muſt be ſo many Parts in the Air, that there may be no Way for the Paſſage of the Light, to cauſe it to be wholly reflected into the Glaſs; but it is plain that there are no ſuch Parts, becauſe Light comes thro' the Air in all Directions quite to the Glaſs. Even in the ſame Place of the Surface which ſeparates the Glaſs and Air, the Light which comes from one Side is reflected, whilſt that which comes from the other Side is tranſmitted. Which clearly proves that the Light is reflected in the very Place where it can go thro'.

790 *Experiment* 3. *Plate* XII. *Fig.* 3.] Every Thing being as in the former Experiment, if the Obliquity of the Light be chang'd, Part of it will paſs thro' into the Air.

Who wou'd conceive that Light, which paſſes from Glaſs into Air, and does not run againſt the ſolid Parts, ſhou'd all of it (by a little increaſing the Obliquity) run againſt thoſe Parts; when in each Medium, as has been already ſaid, there are Pores and Paſſages in all Directions?

791 *Experiment* 4. *Plate* XII. *Fig.* 3.] Take a Glaſs triangular Priſm A B, moveable about its Axis; which is made ſo by fixing braſs Plates to its Ends, with braſs Wires perpendicularly fix'd to them: The Priſm muſt be ſo laid upon the Trough P, as that the ſaid Wires may bear upon the Brims of it, which are made a little hollow to receive them, yet ſo as to let them turn, that the Priſm may move freely about its Axis: Let it be ſo plac'd as to reflect the Light in the ſame Manner, as in the ſecond Experiment. Let the Trough be fill'd with Water up to the Priſm; then the Light, which, ſtriking againſt the

the Air, was wholly reflected, now running against the Water, does partly enter into it, and is only reflected in part.

Which Experiment does not at all agree with a Reflexion made by a Stroke upon the solid Parts.

In the third Part of this Book we shall also shew, that thin Plates, which reflect Light, will transmit it, if they become thicker*. *894

The fourth Experiment also proves that *the reflecting Power is so much greater, as the Mediums, which are separated by a reflecting Surface, differ more in Density*; for Glass and Air differ more in Density than Glass and Water. 792

In this Experiment we also see that *Reflection is made by the same Power by which the Rays are refracted, which produces different Effects in different Circumstances.* 793

A Ray, which goes out of a denser into a rarer Medium, by the Attraction of the former, is made to recede from the Perpendicular*; if the Obliquity of the incident Ray be increas'd, the Obliquity of the refracted Ray will also increase, till it comes at last to move in the very Surface which parts the Mediums. And this obtains, when the Sine of the Angle of Incidence is to the whole Sine, as the Sine of Incidence, in the denser Medium, is to the Sine of Refraction in the rarer; for in that Case the Angle of Refraction is a right one. If the Obliquity of the incident Ray be more increas'd, it is plain that the Ray cannot penetrate into the rarer Medium: This is the Case in which the Light is wholly reflected; which Reflexion depends upon that Attraction by which the Rays are refracted. For when the Ray is moved thro' the Space of Attraction, it is bent towards the denser Medium*; if it be in the denser Medi- *625 *618

um, and ſo bent, that, before it has gone thro' the whole Space of Attraction, the Tangent to the Curve be parallel to the Surface that ſeparates the Mediums, the Curve, being continued, turns back again; and therefore the Ray is reflected by the Attraction of the denſer Medium, and this Continuation of the Curve is ſimilar and equal to the firſt Part, and makes the Angle of Reflexion equal to the Angle of Incidence; becauſe the Light returns thro' the ſame Part of the Sphere of Attraction; and the ſame attracting Force acts upon the Light in correſpondent Points of the two Parts of the Curve. Thus a Projectile, in its Aſcent and Deſcent, deſcribes ſimilar Curves.

Yet that *all Reflexion does not depend upon that*
794 *Attraction, in the ſame Manner*, is evident; for in that Caſe, in which the Refraction is made, Part of the Light is reflected; for the Light does not wholly penetrate out of the rarer into a denſer Medium; for even in that Caſe, in which the Attraction is the moſt oppos'd to the Reflexion that is poſſible, yet ſome Rays are reflected.

Yet it cannot be doubted but that, *in every*
795 *Caſe, Reflexion has relation to the refracting Power.*
796 *Where Light paſſes without Refraction, there it is*
*617, *not reflected* *; *but where the Refraction is greateſt,*
788 *there the Reflexion is alſo ſtrongeſt* *; which is true,
*631, 792 not only when Light, moving in a denſer Medium, ſtrikes againſt a rarer, as in the fourth Experiment; but the ſame Thing is obſerv'd, when Light ſtrikes againſt the denſer Medium: Thus ſuppoſing the Light to move in Air, the Surface of Glaſs reflects more ſtrongly than that of Water; and that of a Diamond yet more ſtrongly. If Glaſs and a Diamond be immers'd in Water; the refracting Power is leſs in the Separation of thoſe Bodies with Water, than where thoſe

those Bodies touch the Air*. These Bodies also *631
reflect Light less strongly in Water than in
Air. From this Relation of the reflecting and refracting Powers, we deduce, that *Light is driven* 797
back at a certain Distance from the Bodies, in the same Manner that the refracting Power does also act at some Distance from the Body: This Proposition is confirm'd from what has been demonstrated concerning Reflexion, which does not depend upon a Stroke made against the solid Parts of Bodies; and this is fully made out, if
we consider, *that polish'd Bodies reflect the Light* 798
regularly (which we observe in Looking-Glasses) *tho' there be a great many Scratches in their Surfaces:* For as they are polish'd with the Powder of *Emery* and *Putty*, tho' their Parts are very small, yet they leave very great Scratches on the Surface in Respect of the Particles of Light; whence in the Surface itself the Reflexion must needs be irregular; but if we conceive the Reflexion to be made at some Distance from the Surface, the Irregularities are diminish'd, and almost wholly taken off, as is easily understood by any one that considers it with Attention.

CHAP. XIV.
Of Plane Mirrors.

Plate XII. *Fig.* 4.] LET *b c* be the Surface 799
of a Plane Mirror or Looking-Glass; A a radiant Point. *Let the Plane of the Glass be continued, and from the Radiant* A *let a Perpendicular* A C *fall upon it*; *if this Line be continued, and* C *a be made equal to* C A, *a will be the imaginary Focus of the reflected Rays that proceed from* A. Let A *b* be the incident Ray; *b f* the reflected Ray; which continue beyond the Glass;

because the Angles of Incidence and Reflexion are
784 equal to one another, their Complements alſo, which are the Angles A *b* C, *f b d* are equal; to this is equal its oppoſite and vertical *a b* C: The Triangles A *b* C, *a b* C, which are rectangular, have the Side C *b* common, and the Angles C *b a*, C *b* A, equal; therefore they agree in all Reſpects, and C A and C *a* are equal to one another: Which Demonſtration may be applied to all other Rays which flow from A, in whatever Plane, perpendicular to the Glaſs, they be conceiv'd to be. Therefore where-ever the Eye is, if the reflected Rays come to it, they will enter the Eye as if they came from *a*; and the Point A will appear
737 in that Place; but *the Appearance of that Point*
800 *will have the ſame Poſition in reſpect of the Mirror, behind it, as a radiant Point has before it.*

801 If this be applied to all the Points of the Object, it will appear, that *the Object will appear behind the Glaſs in the ſame Poſition that it has before the Glaſs.*

CHAP. XV.

Of Spherical Mirrors.

802 EVERY ſpherical Surface may be conſider'd, as made of innumerable ſmall Planes; and a Plane, which touches the Sphere in any Point, is as it were a Continuation of ſuch a ſmall Plane.

803 Spherical Mirrors are either *Concave* or *Convex.*

The firſt are made of Part of an hollow Sphere poliſh'd.

The ſecond are Parts of Spheres poliſh'd on the Outſide.

A Ray coming upon any spherical Mirror, together 804
*with its reflected Ray, is in a Plane, which being continued, goes thro' the Center of the Sphere**, for such * 782
a Plane is perpendicular to the Surface of the Sphere. *A Line which is drawn thro' the Center of* 805
*the Sphere and Point of Incidence, being continued makes equal Angles with the incident and reflected Rays**; for that Line is perpendicular to the * 784
Surface, and those Angles are Angles of Incidence and Reflexion; therefore *the Ray that goes thro' the* 806
Center, or which being continued, would go thro' the Center, when reflected returns upon itself.

Plate XII. *Fig.* 5.] Let *b c* be a Portion of the convex Mirror, A a radiant Point; let A *b*, A *d*, A *c*, be incident Rays, the reflected Rays will be *b f*, *d g*, *c h*; *if from the radiant Point* A *a Tan-* 807
gent be drawn to the Mirror, the reflected Ray will be a Continuation of the Incident, or rather *the Reflexion of the Rays terminated in the Point of Contact.*

If b f, d g, c h, the Rays that are reflected from 808
the convex Mirror, be continued, with all the intermediate ones, by their Intersections they will form the Curve *a a*, which all these Rays touch, and the neighbouring Rays intersect in the Periphery of the Curve; so that they always enter the Eye as if they came from a Point of the Periphery; *in which* therefore *the Point* A *does* always *appear**, * 737
as long as the reflected Rays can come to the Eye, and the Eye is mov'd in a Plane which goes thro' the Center of the Sphere; but when the Eye is mov'd out of that Plane, the Radiant appears in another Curve, because there are such Curves in every Plane, which may be conceiv'd to pass thro' A and C.

Since all these Curves, and each of them whol- 809
ly are behind the Glass, *all the Objects* also *appear behind the Surface of the Glass.*

The

810 *The Objects likewise appear erect.* For if the Point A be mov'd about the Mirror, the whole Curve *a a* is carried with the same Motion; which proves (in respect to the erect inverse Situation) that the Points of the Representation have the same relation to each other as the Points of the Object itself.

As the Point A is farther removed from the Glass, the whole Curve does also recede by a contrary Motion; but supposing A at an infinite distance, that Point of the Curve which is the farthest remov'd from the Surface, will be distant from a quarter of the Diameter; whence it fol-
811 lows, that *the Objects appear diminish'd*, because all the Representations are compriz'd in small Limits.

812 *If the Eye be mov'd, the Appearance of the Object is also mov'd, and its Figure chang'd*; for all the Points are mov'd in their own Curves, and that unequally, according to the different Situation of the Eye in respect of each Curve; whence of necessity the Figure must be chang'd.

Experiment 1. *Plate* XII. *Fig.* 6.] If any one sees his Face in a spherical convex Mirror standing at A, he will see his Face at *a* erect, diminish'd and unlike; by the Motion of the Eye one may observe the other things mention'd in respect to fix'd Objects.

813 Let *b d* (*Plate* XIII. *Fig.* 1.] be a *concave Mirror*, and a Portion of a Sphere whose Center is C; *let parallel Rays fall upon the Surface of the Mirror*, one of which, C *d*, is suppos'd to pass thro' the Center; this Ray by Reflexion returns upon
* 806 itself*, and the Rays next to it being reflected, become converging, and concur with it in the Focus F, which is the middle Point between *d* and C. Let A *b* be a Ray very little distant from C *d*; draw the

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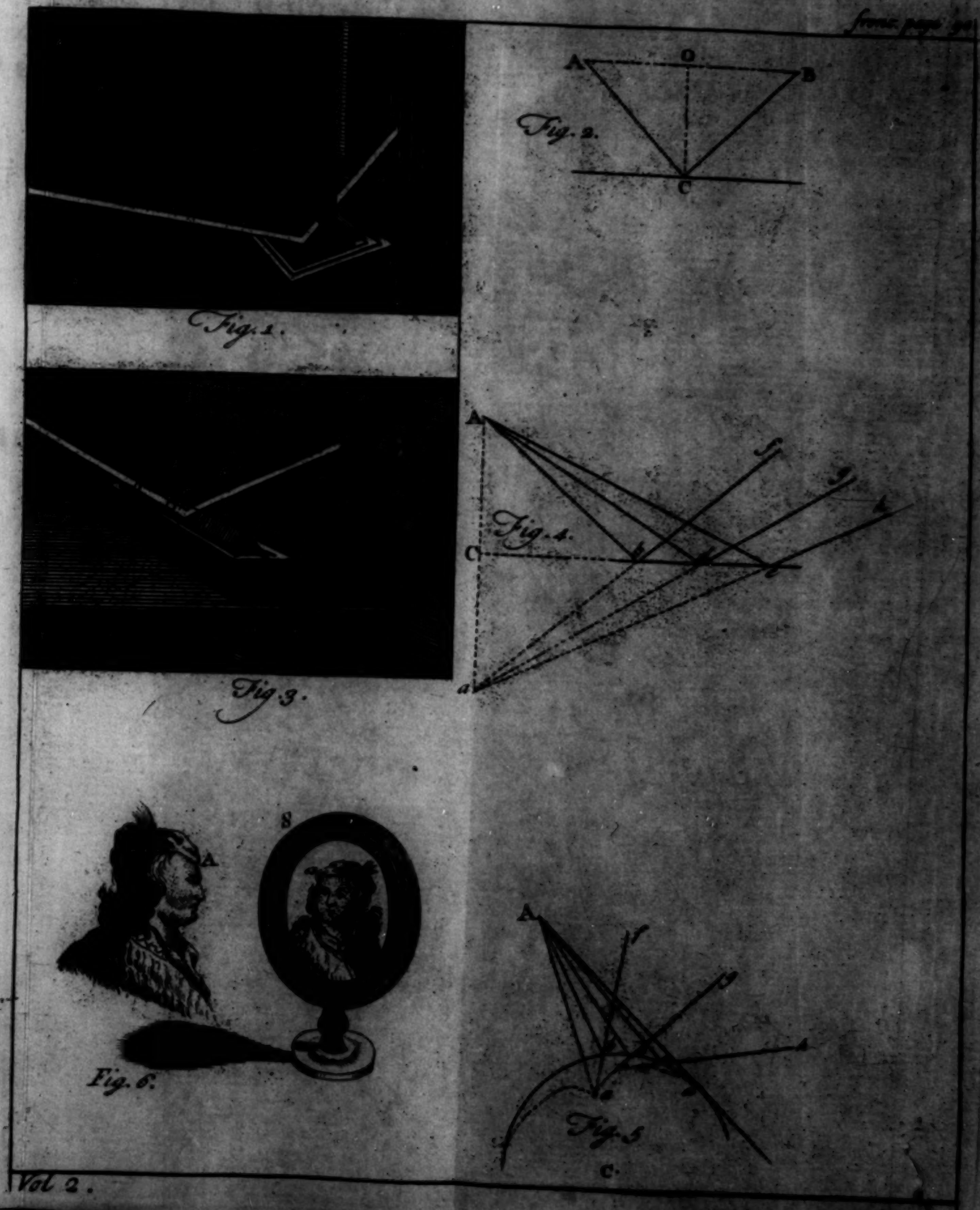
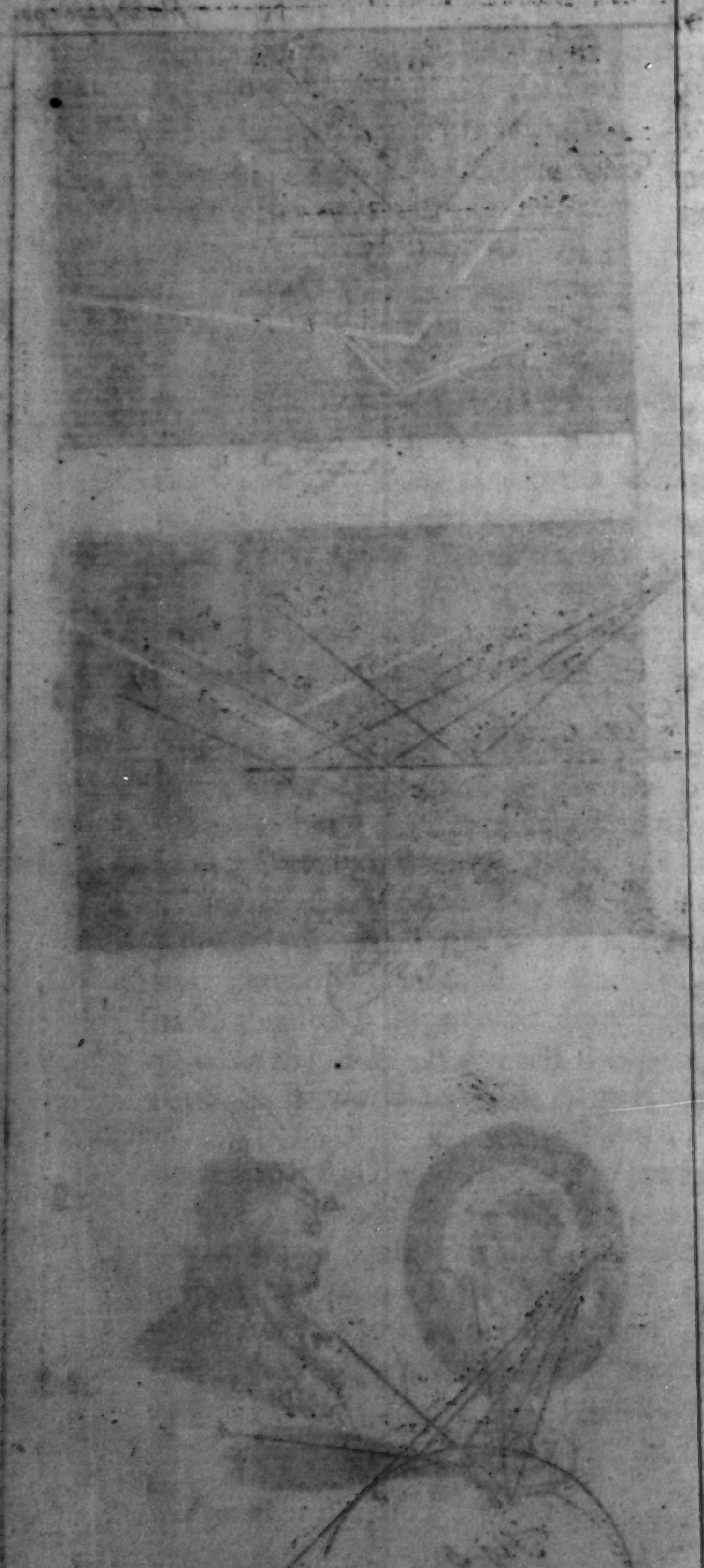




the Semidiameter C *b*; the Angle of Incidence will be A *b* C, to which the Angle of Reflexion C *b* F* is equal, as alſo the alternate Angle *b* C F; * 805
therefore *b* C F is an Iſoſceles Triangle, and the Sides F C and F *b* are equal; becauſe *b d* is very ſmall, F *d* and F *b* do not ſenſibly differ, therefore F C and F *d* are equal; which Demonſtration will ſerve for all the Rays that are but very little diſtant from C *d*.

If parallel Rays are farther diſtant from C *d*, they do not meet at F; yet they will all come together into a little Circle, if the Diameter of the Mirror does not exceed the fifth or ſixth Part of the Diameter of the Sphere of which it is a Portion.

Burning Mirrors are made upon this Foundation, which collect the Sun's parallel Rays into a Focus. 814

Experiment 2. *Plate* XIII. *Fig.* 2.] Let there be a concave Mirror S, made of Metal, or of Glaſs quick-ſilver'd behind; let it ſtand upon the wooden Foot P, whoſe upper Part is bor'd ſo as to receive a Cylinder of Wood made faſt to a tranſverſe Piece A A, which ſerves for turning the Glaſs round with a horizontal Motion; and the Mirror itſelf muſt move upon two Ends of an Axis between the Pillars A B, A B, ſo as to be inclin'd in any Angle, and the Screws B, B, will make it faſt in any Poſition.

Having expos'd the Burning-Glaſs to the Sun Beams in ſuch a manner, that the Ray, which comes upon the middle of the Glaſs, is perpendicular to its Surface, ſince all the others are parallel to it, they are collected in a Focus, at a quarter of a Diameter's diſtance from the Glaſs, and there burn violently.

If

If the Diameter of the Surface of the Mirror (as it is in mine) be of about 15 Inches, and the Focus is 18 Inches diſtant from it, Wood will immediately be in a Flame, and thin Plates of Lead preſently melt.

If we conſider the Rays that are at ſome diſtance from C *d*, and parallel to it, thoſe of them that are neareſt one another being reflected, will interſect before they come to C *d*, and in that
815 Caſe, that is, *where parallel incident Rays fall obliquely on the Glaſs, being a little diſperſed by Reflexion, they are collected in a Point.*

816 *If the Focus, in which parallel Rays are collected by a concave Mirror, becomes the radiant Point,* the Rays, which are but little diſperſed, are reflected
* 813 parallel to one another *.

785 From theſe Properties of a concave Mirror we
817 deduce the Method of repreſenting Objects in a dark Place, much like what was before ſhewn in
* 711 reſpect of a convex Lens *.

Plate XIII. *Fig.* 3.] Let there be an Hole F thro' the Wall; let a b be a concave Mirror, ſo plac'd as to collect the parallel Rays that are perpendicular to the Wall at F; the Rays coming
* 816 from F in that Direction, are reflected *; and ſuch are the Rays, which being reflected from the external Objects, interſect one another at F.

Let A F be Rays coming from a Point of a diſtant Object; theſe Rays are by the Mirror reflected perpendicularly to the Wall; and becauſe Rays coming from a diſtant Point, and paſſing thro' a ſmall Hole, may be look'd upon as parallel, theſe Rays will, after Reflexion, be collected into one Point at *a*, at the diſtance of
* 815 the Wall *, that is, in its Surface; where therefore the Point will be repreſented. In the ſame manner the Rays which come from a Point thro'

thro' B F, are collected at *b*; which, as it is true with regard to all the Points of an Object, will give the Representation of it upon the Wall; and if the Wall be white, and the Object enlighten'd by the Rays of the Sun, the Picture will appear in very lively Colours.

Experiment 3. *Plate* XIII. *Fig.* 4.] In a dark Place cover the backside of the Window-shut with white Paper, an Hole being made in the middle of it little more than half an Inch diameter, so as to answer to an Hole behind it in the Window-shut, over-against which, at a distance no less than of 50 Foot, there are several Objects enlighten'd by the Sun; let a concave Mirror, whose Surface is 15 Inches wide, and which collects parallel Rays at the distance of 18 Inches, be plac'd at that distance from the Window, in such manner, that a Line passing thro' the Center of the Hole, and the Center of the Surface of the Mirror, be perpendicular to the Plane of the Paper and the Surface of the Glass; then the Objects will be represented upon the Paper in a Circle concentric with the Hole, and whose Diameter is equal to the Diameter of the Mirror; you must join to the Hole, on the outside of the Room, an hollow truncated Cone, to exclude the Light which does not come from the Objects to be represented.

Let *b e (Plate* XIII. *Fig.* 5.) *be a concave Mirror*, C the Center of its Concavity, A *a radiant Point farther distant than* C *the Center of the Glass*; A *b*, A *d*, A *e*, incident *Rays*, whose *reflected* ones *bf*, *dg*, *eh*, with their intermediate ones, *by their mutual Intersections form the Curve a a, which they touch*; therefore *the Point* A *appears in that Curve* *; and if the Eye be mov'd in the Plane of the Curve, the Appearance will change

Place

Place in that Curve. But in all the Planes which may be conceiv'd to paſs thro' C A, there is ſuch a Curve, and they all concur in the Line C A,
819 namely, at the Point *a*; *therefore in that Point a, the reflected Rays are the moſt abundantly collected*, which therefore is call'd the Focus of the Rays coming from A. On the contrary, A will be the
* 785 Focus, ſuppoſing the Radiant at *a* *.

In this Figure there is only part of the Curve drawn, which is produc'd by one Part of the Line A C; ſuch another Part muſt be conceiv'd on the other ſide, and both join in the Focus of the radiant Point.

820 *As the radiant Point recedes, the Curve comes nearer the Mirror.*

821 As the Radiant comes forward, the Curve recedes from the Mirror, and moves towards the Radiant, till they concur *at the Center* C; in which, *if the Radiant be plac'd, all the reflected Rays*
* 806 *will coincide with the incident* *, and the whole Curve will, as it were, be ſwallow'd up in the Center.

822 *If the Radiant* is yet brought nearer to the Mirror, ſo as to *be between the Center and the Glaſs, the Curve will* recede farther, and *be* then *beyond the Center*; and in the Curve, that Point will recede moſt of all, in which all the Curves concur which are conceiv'd in ſeveral Planes, that is, the Focus of the radiant Point; and that Focus
823 will be at an infinite diſtance, *when the Radiant is diſtant from the Mirror juſt the fourth Part of the*
* 813 *Diameter of the Sphere* *; then alſo *the Curve is*
816 *extended* in infinitum, *and the two Parts* which concur in the Focus of the Radiant *are ſeparated*; this ſeparated Part is ſeen at a a: (*Plate* XIII. *Fig.* 6.) *If the Radiant be brought ſtill nearer, the curve Parts decline from one another*, becauſe the
824 Rays, ſuch as A *b*, and thoſe nearer it, being reflected,

flected, do not touch the Curve, but become divergent; that is, those reflected Rays being continu'd beyond the Glass, will intersect one another, *and form a new Curve behind the Glass, which has two Legs,* one of which is seen at *a a*; they concur in the Line C A continu'd, namely, at *a*, and receding from the Glass, are stretch'd out *in infinitum.* And there is also on each side of the radiant Point, a Point in the Surface as *d*, which separates the Rays that form the Curves *a a* and a a; and the Ray A *d*, being reflected in *d* g, touches neither of the Curves, if it be infinitely continu'd toward each Part g, g, tho' it is continually coming nearer to each Curve. If the whole Sphere was compleated in respect of the opposite Part of the Sphere, the Radiant would be beyond the Center, and the reflected Rays would form the Curve which we have mention'd before, * by which the separated Legs, as a a, * 818
would be join'd. These things thus premised, we proceed to explain the Phænomena of concave Mirrors.

If the Mirror be enlighten'd by a lucid Body, the 825
Rays which come from all the Points of the Object being reflected, will form Curves, but *are chiefly collected in the Foci of these Points*; * therefore *if these* * 819
Foci are in the Surface of a white Plane, there will 826
be upon it a Representation of the lucid Body, as in the second *Experiment* of *Chap.* IX. and that Representation will be *inverted,* for the Line which joins the radiant Point with its Focus, goes thro' the Center of the Sphere; * in which therefore * 819
all such Lines intersect one another; and this Intersection is between the radiant Point and the Focus, * in which the Point is represented. * 818

But as the lucid Body is brought nearer to the Mirror, the Appearance recedes farther, * *and* in this * 820
Case *becomes bigger.*

Experi-

Experiment 4.] Hold a lighted Candle between the Mirror and the Center of the Sphere of which it is a Portion, yet ſo that it may be more diſtant from the Mirror than that Center; if then there be a white Plane perpendicular to the Line that paſſes thro' the Candle and the Center of the Mirror, and this Plane be held beyond the Center, you will have upon it an inverted Repreſentation of the Candle; the proper Place will be found by moving the Plane forwards and backwards; as likewiſe by this Proportion, *viz.* As the difference of the Diſtances of the Candle, from the Center of the Sphere and from the Mirror, is to the fourth Part of the Diameter of the Sphere, ſo is the Diſtance of the Candle from the Glaſs to the Diſtance required. As the Candle is brought nearer to the Speculum, the Plane muſt be mov'd farther off, and the Repreſentation will grow bigger.

827 *Plate* XIII. *Fig.* 5.] *Objects placed beyond the Center, appear between the Glaſs and the Center*; for all the Points appear in a Curve, as at *a a*;
* 818 * *the Images of the Objects will alſo be diminiſh'd and*
828 *inverted*, for they are reduc'd into a narrow Space; and as the Point A moves downwards, its Repreſentation will be carried upwards; for the Line *a a* keeps the ſame Situation in reſpect of A C *a*, as it is carried round the Center C.

Experiment 5. *Plate* XIII. *Fig.* 7.] Leſt the Repreſentation of the Object ſhould be leſs vivid, the Mirror is to be included in a Box. If you have a Mirror, whoſe Surface is about eight Inches wide, and which is a Portion of a Sphere of a Foot and a half in diameter, ſhut it up in a Box P, in whoſe fore-part there is an Hole

of about 6 Inches Diameter, and from which the Glaſs is diſtant about 6 or 7 Inches; and let this Opening be turn'd from the Light. Now if any Perſon, as A, beholds himſelf at the Diſtance of about 2 Foot from the Glaſs; his Face will appear inverted in the Box towards the Hole; and if the Beholder comes nearer, he will ſee a Head coming out of the Hole.

The Repreſentation of a Point, placed in the Cen- 829
*ter of a Sphere, coincides with the radiant Point itſelf, and is as it were ſwallowed up by it**. *821

If the Eye be plac'd in that Center, no Object can 830
be ſeen by it; for then only the Rays, that flow from the Eye, will be reflected to it*. *806

If the Object be between the Center and the Point, 831
*in which parallel Rays are collected after Reflexion, the Object will alſo appear without the Glaſs, at a greater Diſtance from the Glaſs than the Object itſelf**; *the Repreſentation is inverted*; which is pro- *822
ved in the ſame Manner as in N°. 828; *and magnified*, becauſe it is farther remov'd from the Center, than the Object itſelf is diſtant from it; for the Repreſentation recedes from the Center *in infinitum*; whilſt the Object goes thro' the fourth Part of the Diameter of the Sphere.

If the Object be leſs diſtant from the Mirror than 832
the fourth Part of the Diameter of the Sphere, according to the different Situation of the Eye, the Object appears either before or behind the Glaſs.

Plate XIII. *Fig.* 6.] If the Eye be ſo plac'd, that thoſe Rays may come to it which form the Curve *a a*, as towards *f*, it will ſee the Appearance of the Objects towards the Glaſs * magni- *824
fied; becauſe the Curves, as *a a*, which belong to ſeveral Points, are diverging.

If thoſe Rays come to the Eye which form 833
the Curve *a a*, the Object will appear without the Glaſs: And *in both Caſes the Repreſentation is*

erect; for as the Point A ascends or descends, the Curves *a a* and a a, in which it is represented, are agitated with the same Motion.

834 *If the Eye be* in the Point, in which the reflected Rays, that belong to each Curve, intersect one another, *as in* O, *the Appearance of the Object will be double.*

It is plain in every Case of the Appearance, that the Points have not the same Relation to one another, as the Points of the Object; and

835 therefore that a *Concave Mirror never represents the Objects exactly*: But the most irregular Representation of all is that which is in such Lines, as a a.

836 There are also cylindric Mirrors convex and concave; these in one Respect are plane, and in another Respect spherical; and therefore the Representation of the Objects is very irregular: which Irregularity, since it depends upon a regular Figure, may be so determin'd, that Pictures may be drawn, which, tho' truly irregular, will in such a Glass appear regular by Reflection, in a determinate Situation of the Eye.

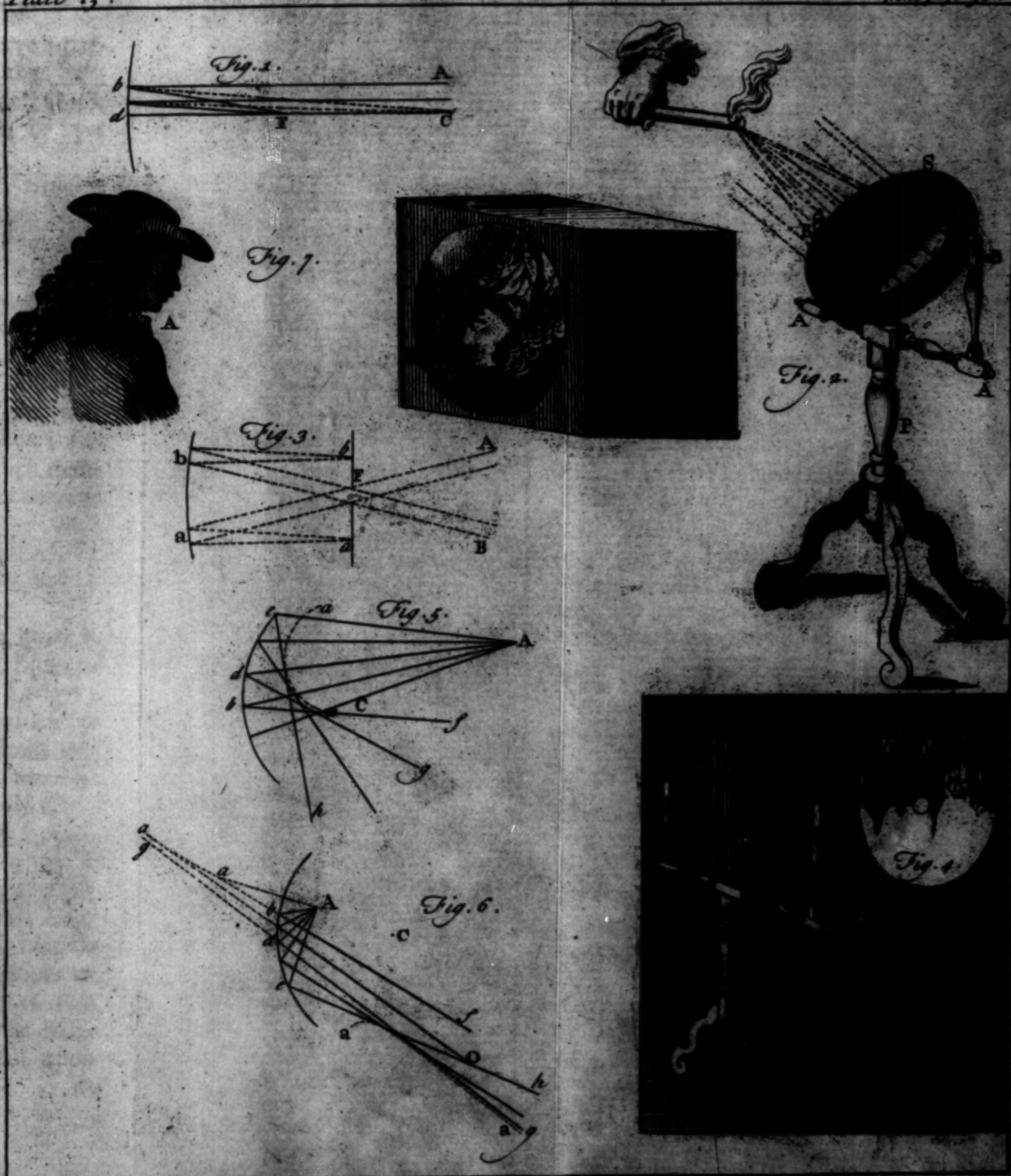
CHAP. XVI.

Of the Magic Lantern.

THERE are several Machines made by the Combination of Mirrors and Lenses, which afford useful and pleasant Appearances; whose Explanation may be easily deduced from what has been said.

Among many other I shall only chuse to explain one, in which Figures, that are painted upon small Pieces of Glass, are represented monstrously large upon a white Plane. This is a Phæno-

Plate 13. front page 98.



Phænomenon wonderful enough to deſerve a particular Explanation; the Inſtrument that performs this is call'd a *magic Lantern*, which Optic Writers have not altogether paſs'd by, but yet have not ſufficiently explain'd.

Plate XIV, *Fig.* 1.] Let there be a wooden Box about a Foot and half long, 14 Inches high, and as wide; there muſt be a concave Mirror S of 8 Inches diameter, and a Portion of a Sphere of 18 Inches; this Mirror is fixed to a Foot which moves upon Rulers along the Length of the Box. 837

There is alſo in this Box a Lamp L, ſuſtain'd by a wooden Foot, which is moveable long-wiſe between two Rulers, in the ſide of the Box; the Pipe of the Lamp ſtands forward, in ſuch manner that the Center of the Flame is over-againſt the Center of the Surface of the Mirror; this Flame is made up of four little Flames, which by touching one another, make one ſquare Flame two Inches wide.

In the top, or upper Plane of the Box, there is an oblong Hole, which has a Cover that ſlides to two Grooves, or between two Rulers or Ledges; thro' this Cover paſſes the Chimney C, which (as you ſee in the third Figure) ſtands up about half a Foot above the Box; the Chimney is moveable with the Cover, whilſt the Opening remains ſhut, that the Chimney may be always over the Lamp.

In one of the little Sides of the Box, which is over-againſt the Mirror, there muſt be a round Hole about five Inches wide, which muſt have in it a convex Lens of Glaſs of the ſame bigneſs V, convex on both Sides, which are Portions of a Sphere of one Foot diameter; the Axis of this Glaſs being continu'd to the Surface of the Mirror, will be perpendicular to it, and fall upon

its Center, as likewiſe to the Plane of the Flame, thro' whoſe middle Point it alſo paſſes.

This Hole is ſhut and open'd by a Plane moveable in a Groove, which is mov'd by a Cylinder that ſtands out of the Box at E.

To this Hole without the Box anſwers the Tube T, whoſe Length and Diameter is of about ſix Inches, at the end of which there is a Ring, in which the ſecond Tube *t* moves, of about four Inches diameter, and five or ſix Inches long.

In the leſſer Tube there are two Lenſes, the firſt in that End which is thruſt into the Tube T, and it is of the ſame Convexity as the Glaſs V, and three Inches and a half diameter; the ſecond Lens is three Inches from the firſt, and flatter, being terminated by Portions of a Sphere of four Foot diameter; between theſe Lenſes, at the diſtance of about an Inch from the ſecond, there is plac'd a wooden circular Stop or Aperture, which ſhuts up all the Tube, except an Hole of an Inch and a quarter diameter in the middle of the Wood.

The Objects that are to be repreſented, are to be painted upon a flat thin Piece of Glaſs, which muſt be mov'd without the Box over-againſt the Glaſs V, between it and the Tube T, the Picture being in an inverted Poſition; if theſe Pictures are round, they may be of five Inches diameter; that they may be mov'd eaſily, they are put into flat Boards, three in a Board; the Picture alſo may be painted upon long Glaſſes, which may be ſucceſſively made to ſlide before the Glaſs V.

Plate IV. *Fig.* 3.] This whole Box ſtands upon a Frame or Foot, made ſo that it may be fix'd at different Heights; there are flat Pieces of Wood fix'd to the Box at bottom, which ſlide in Grooves in the Frame; each of them has a Slit in it, ſo that

that the Box may be made faſt at any deſired Height, by the help of Screws join'd to the Frame, and moveable in the Slits.

The whole Machine is plac'd at the diſtance of 15, 20, or 30 Feet from a white Plane, which Diſtance muſt be different, according to the bigneſs of the Plane; for this Diſtance may be equal to the Length of the Plane; the Box muſt be juſt at ſuch an Height, that the Tubes in the ſide of the Box may be exactly oppoſite to the middle of the Plane.

The Lamp being lighted, the Box muſt be ſhut, and the Figures which are painted upon the Glaſs will be repreſented upon a white Plane; by moving backwards and forwards the Tube that has the two Lenſes in it, you will find the proper Poſition of the Glaſſes required to give a diſtinct Repreſentation. As for the Diſpoſition of the ſeveral Parts of the Machine, which immediately ſerve for exhibiting this Appearance, we ſhall here more particularly explain.

Plate XIV. *Fig.* 2.] The Parts in this Figure 838
are ſhewn ſeparately; S S is the Mirror, *l l* the Flame which conſiſts of four Flames in the Line *l l*; V V is the Glaſs V of the firſt Figure; O O is a Picture painted upon a flat thin Piece of Glaſs; *a a* the biggeſt Lens; *d d* the flatteſt Lens; *b b* the wooden Stop between the Lenſes; *f* the Aperture or Hole in the middle of the wooden Circle.

Theſe things being diſpos'd as has been already explain'd, and as may be ſeen in the Figure, the Rays which proceed from a Point of the Picture O O, by going thro' the Lens *a a*, become leſs diverging, and fall upon the Lens *d d*, as if they came from a Point more remote*; from this * 669
Lens they go out more converging*, and are * 699
collected upon the Surface of the white Plane,

where they exhibit the Point of the Picture that
* 711 is painted on the Glaſs *; this Picture is illuminated both by the Rays that proceed from the Flame $l\,l$, and by the Rays reflected by the Mirror S S.

839 For the Perfection of this Machine, it is required, 1*ſt*, that the Figure O O be enlighten'd as much as poſſible; 2*dly*, that it be equally enlighten'd in all its Points; 3*dly*, that all the Light by which every Point of the Picture is enlighten'd, go thro' the Lenſes *a a* and *d d* to the white Plane, and ſerve to make the Repreſentation; 4*thly*, that no other Light but that go out of the Box, leſt the Repreſentation ſhould be leſs lively by reaſon of extraneous Light.

The firſt Requiſite depends upon the Bigneſs of the Flame, and of the Mirror, and of its Concavity; the more concave it is, the nearer it is to be brought to the Flame, and then the more Rays will be intercepted and reflected; yet Care muſt be taken that the Mirror (which may be made of very good Glaſs) be not too much heated.

When the Flame and Mirror are ſo contriv'd, that the Picture is the moſt enlighten'd that it can poſſibly be, and every where equally enlighten'd, the Flame and Mirror muſt be ſo plac'd, that the inverted Image of the Flame ſhall fall juſt
* 826 upon the Picture *. Now as the Repreſentation
* 826 of the Flame can be increas'd and diminiſh'd *, the Mirror and Flame muſt be ſo diſpoſed, that the Repreſentation of the Flame ſhall cover the whole Picture upon the Glaſs, but ſo as not to exceed it; for then the Picture is as much enlighten'd by the reflected Light as it can be, and all its Points are equally illuminated; the direct Light alſo does pretty near equally fall upon all the Points of the Picture; this Light would indeed be increas'd by bringing the Flame nearer,

but

but the reflected Light would be diminiſh'd, and the Diminution of this laſt would be greater than the Increaſe of the other.

The Glaſs V V ſerves to inflect the Light, by which the Picture O O is illuminated, before it comes to the Picture; by which Inflection all the Light comes to the Lens *a a*, and ſerves for the Repreſentation on the white Plane.

All the Light that is of uſe for this Repreſentation goes thro' the Hole *f*, and the Rays coming from different Points, interſect one another there; wherefore the Picture upon the Glaſs, which is plac'd inverted, is repreſented erect upon the white Plane; by the Ring *b b*, all the Rays which do not ſerve to form the Repreſentation, are intercepted, leſt they ſhould enter the Room, and make the Picture leſs diſtinct; this Ring or Aperture alſo intercepts thoſe Rays by which one Point is more enlighten'd than another, whereby the Light, which (from what has been ſaid) is equally enough diffus'd, is yet made more equal; but unleſs the Stop or Aperture *b b* be juſt where the Rays interſect, it does a great deal of Miſchief.

BOOK III.

PART III.

Of Opacity and Colours.

CHAP. XVII.

Of the Opacity of Bodies.

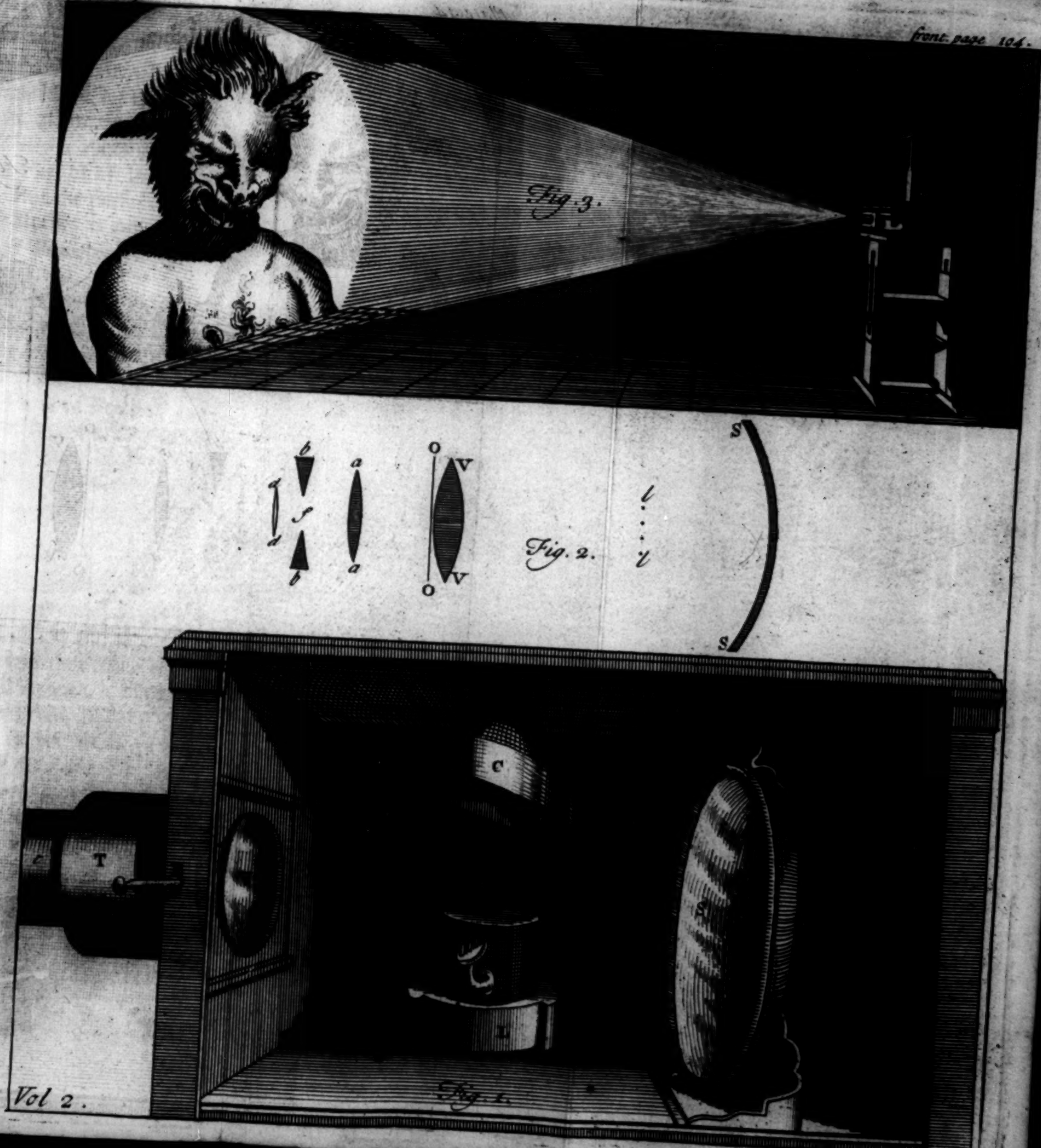
DEFINITION.

840 BODIES *that transmit the Light are called* transparent; such are all
* 615 Mediums *, except a *Vacuum*.

841 *There is no Body, whose smallest Parts are not transparent*; no one who is used to Microscopes will doubt of this. There are some Parts of Metals, which, tho' very small, do not transmit the Light; but if they be dissolv'd in *Menstruums*; that is, if they be divided into much less Parts, they become transparent. One may also prove by a very easy Experiment, that Light cannot go thro' several opake Bodies.

Experi-

Plate 14



Experiment 1.] In a dark Room, in which the Sun's Light comes in thro' an Hole, let that Hole be cover'd with a thin Plate of an opake Body, and the Light will go thro' it; a Piece of Wood of the thickneſs of the tenth Part of an Inch, does not intercept all the Light. But the perfect Tranſparency of Parts in opake Bodies is not prov'd by this Experiment, for that Tranſparency is only in very ſmall Parts.

Opacity does not (as is commonly imagin'd) *hap-* 842
*pen in Bodies, becauſe the way thro' which the Light
might paſs is ſtopt by Particles of Matter*; for Light
paſſes thro' all the ſmalleſt Parts of Bodies; nei-
ther is ſuch an Interception of Light of any uſe to
cauſe Opacity: It is required for Opacity that
the Light ſhould be reflected and deflected from a
right Line, for which there is only required the
Separation of two Mediums*. * 631
796

Let us conceive a Body, conſiſting of very
ſmall Parts, perfectly tranſparent (ſuch as are the
Particles of which Bodies conſiſt*) and ſeparated * 841
from one another by Pores, and that thoſe Inter-
ſtices are either void, or fill'd with a Medium
whoſe Denſity is different from that of the Parti-
cles; if Light enters ſuch a Body, it will every
Moment fall upon a Surface dividing Mediums
differing in Denſity, therefore it will undergo
innumerable Reflexions and Refractions in that
Body*, ſo as not to be able to get through it; * 631
therefore we ſee that *Opacity depends upon the Pores*, 796
for *if you fill the Pores with a Medium of the ſame* 843
Denſity as the Particles of the Bodies themſelves, the
Light will undergo no Reflexion or Refraction in
the Body, but paſs directly thro'*, and *the Body* * 841
will be tranſparent. 631

Tho' 697

Tho' we cannot make Experiments, whereby to fill the Pores of the Body with a Medium exactly of the same Density as the Particles, yet the following Experiments will clearly enough prove Sir *Isaac Newton*'s Doctrine concerning Opacity.

Experiment 2.] Paper becomes more transparent when moisten'd with Water, for it fills the Pores, and differs less in Density from the Particles than Air does. Oil has the same Effect.

Experiment 3.] Take a Piece of Glass two Inches thick, and take several Plates of the same Sort of Glass laid upon one another, yet so as not to be quite two Inches thick, and you will find that these will be less transparent than the solid Piece, because of the Air between the Plates, which does not get into the solid Piece where all the Parts cohere.

Experiment 4.] Take twelve Plates of the same Glass, as near as may be of the same thickness; let six and six of them be laid together; if you take the least transparent of those two Particles, and having dipt it in Water, take it out again, it will become more transparent than the other; because the Water, which in that Case fills the Interstices between the Planes, differs less in Density from the Glass than Air does.

What has been said of Opacity is farther confirm'd, and put out of all Doubt by innumerable
844 Experiments, by which *Bodies perfectly transparent become opake, by the Separation of their Parts*, without the Intervention of any opake Body.

Experi-

Experiment 5.] Let any perfectly transparent Liquid, that may be chang'd into Froth, be shak'd till it be full of Bubbles, it will immediately become opake, by reason of the Interstices that are fill'd with Air.

Experiment 6.] Turpentine and Water are transparent Bodies, but when mix'd they become opake.

Experiment 7.] Water and Oil, by being mix'd together, become opake, tho' singly they are transparent.

Experiment 8.] Tho' Glass be transparent, yet if it be reduc'd to Powder it becomes opake, as it also does when it is crack'd.

We clearly see in all these Cases that Opacity is produc'd, because there is a Medium of different Density between the transparent Parts; which may also be observ'd in the Clouds, which are opake on account of the Air interpos'd between the Particles of the Water.

If we add to this what is said in the 22d Chapter following, concerning the Colours of thin Plates, we shall have new Experiments, by which alone it is fully prov'd that Bodies intercept the Light, because they consist of very thin Particles, encompass'd with a Medium differing from them in Density.

Some opake Bodies reflect a little Light, and the rest of the Light, by innumerable Divisions which it undergoes in the Reflexions and Refractions above-mention'd, is extinguish'd in the Body; such are black *Bodies*; if there were any Bodies *perfectly black*, they *would reflect no Light*; 845
for all Bodies, when no Light falls upon them,

and

and therefore they reflect no Rays, appear black.

Other opake Bodies appear to have various Colours; some transparent Bodies are also ting'd with Colours; and whence those arise we are now to examine.

CHAP. XVIII.

Concerning the different Refrangibility of the Sun's Rays.

BOdies appear differently colour'd, tho' they be enlighten'd by the same Rays of the Sun which are reflected by them. Besides these there are several Phænomena of Light relating to Colours, not to be overlook'd.

846 In these we are to observe three things. 1*st*, The Rays are to be examin'd. 2*dly*, Their Reflection is to be observ'd. 3*dly*, We are to enquire into the Constitution of the Surfaces of Bodies differently colour'd.

847 As to the Rays, the first Property to be taken notice of here is, that *in the same Circumstance all Sorts of Rays do not undergo the same Refraction.*

DEFINITION I.

848 *The Rays which undergo this different Refraction, are said to have a* different Refrangibility, *and those are said to be* most refrangible, *which are most inflected by Refraction.*

DEFINITION II.

849 *Those Rays are said to be* homogeneous, *which do not differ from one another in Refrangibility.*

DEFI-

DEFINITION III.

And those are called heterogeneous, *which under* 850
the same Circumstances are not equally inflected by Refraction.

Plate XV. *Fig.* 1.] Between A B and C D let there be a Sun Beam made up of an innumerable Quantity of parallel Rays; these are not equally refracted; for if they fall obliquely on the Surface B D of the denser Medium, some of them are refracted between B E and D G, and are moved according to that Direction in the denser Medium; others are more inflected, and direct their Motion between B F and D H according to the Direction of those Lines; and indeed no Direction can be conceiv'd between the Mediums, along which the Rays do not move in every Point between B and D; so that the least Beam whatever is, by Refraction, divided into an innumerable Quantity of Rays; because every Sun Beam, however small, is heterogeneous, and consists of an innumerable Quantity of Rays refrangible in all Degrees of Refrangibility.

The above-mention'd parallel Rays falling up- 851
on a plane Surface, by Refraction are mov'd between B E and D H; which Lines diverge from each other, and being continued, are more and more separated; so that the Rays above-mentioned are dispersed by Refraction. In N°. 653. *we have consider'd the Rays as homogeneal,* as also every where *in the foregoing Part*; the difference of Refrangibility is small enough in the Rays of the Sun, not to have been worth observing in the foregoing Propositions. Besides, we were first to examine what happens in homogeneal Rays; and what must be chang'd in the Propositions, upon account of the different Refrangibility, will easily appear.

That

852 That this Refrangibility of the Rays may be made visible, the above-mention'd Divergence must be increased; which will be performed, if the Rays above-mentioned fall upon the Surface E H, which terminates a denser Medium, and separates it from the rarer Medium, and which makes any Angle with the Surface B D, and is so inclin'd to it, that the Rays, which are more refrangible, fall more obliquely upon it than those that are less refrangible; so that the former going into a rarer Medium, are more turn'd out of the way, and diverge more from the others upon a double Account, that is, both upon the account of a greater Refrangibility, and of a greater Inclination. The Rays between B E and D G, which are the least refrangible, being refracted a second time, continue their Motion between E I and G L, the others between F M and H N; in which Case, if these Rays fall upon a Plane at the distance of 15 or 20 Foot, those that are most refrangible will be separated from those that are least refrangible, and the whole intermediate Space is enlighten'd with Rays endow'd with a mean Refrangibility.

Experiment 1. *Plate* XV. *Fig.* 2.] Let there be an Hole in the Plate of a Metal in the Window-shut of about a quarter of an Inch, thro' which a Sun Beam enters the darken'd Room; let this Beam fall upon a triangular Prism of Glass A A, in such manner that it may be wholly reflected by the lower Surface (see the *Expr.* of N°. 789.) By the two Refractions which the Light undergoes, Rays that are differently refrangible do not diverge, and being reflected, come upon a second Prism B B, which is likewise of Glass, and triangular, in the same manner as if they had come directly from the Sun. These two Prisms are

 moveable

moveable about their Axes, as we before explain'd *; the first, A A, is laid upon a piece of Wood fasten'd to it, yet so as not to hinder it from turning about its Axis; this piece of Wood is fastened to a three-legg'd Staff with a Ball and Socket, such as is used in practical Geometry. The second Prism, B B, is laid on a Frame or Stand S, in whose opposite Sides there are several Slits that answer one another; by these the Prism is sustain'd at different Heights, but always horizontally, the End of the Axis being plac'd in correspondent Slits.

* 197

The Light that comes to the Prism B B, moves perpendicular to its Axis, and passes thro', as is demonstrated in *Fig.* 1. in which B D and E H represent the Sides of the Prism; the Light is also equally inclin'd to each side, which will happen by moving the Prism about its Axis; for the Light of the Sun (as you move the Prism) will ascend, and then descend again; and the Situation required is that in which the Light is highest of all: now both the Prisms are to be so disposed, that in this Case the Light may go horizontally out of the Prism B B. This horizontal Beam, at the distance of 15 or 20 Foot, must fall upon the Board T, which is covered with white Paper, and has such a Foot, that upon it it may be raised and fixed at different Heights; the Rays come diverging to the Paper, and upon it form the oblong Image R V, terminated at the Sides by parallel Lines, but semicircular at R and V.

If the Rays of the Sun that go thro' the round Hole, fall upon a Plane at a certain distance, they will form a bright round Spot, so much the greater as the Plane is more distant from the Hole, which arises from the Rays that come from the Sides of the Sun, which making an Angle

Angle with those that come from its Center to the Hole, and intersecting them in the Hole, gives the Image of the Sun upon the Plane.

If the Rays did not go thro' the Prism BB, and fall upon the Plane at the distance of the Board T, the Image of the Sun would have its Diameter equal to the Breadth of the Image V R; which
853 Breadth is not alter'd by the Refraction, because the Rays enter the Prism perpendicular to its Axis, and in respect of the Breadth of the Image, are not inclined to it. But as in another respect the Image of the Sun is oblong, it follows plainly from thence, that all the Rays have not undergone the same Refraction; for homogeneous Rays, tho' refracted, will give a round Image of the Sun. The least refrangible Rays go to R, and the most refrangible to V; and the whole Image R V is terminated with Semicircles at R and V, because the whole Image consists of circular Images. Now between R and V there are innumerable Quantities of circular Images, made by Rays of all possible Refrangibilities; otherwise the Image R V would not be terminated with rectilinear Sides.

854 In most Experiments we have said that the Light is let into the darken'd Room thro' a Slit or an Hole, which we leave to the Contrivance of the Workman; our Method was the following.

Plate XV. *Fig.* 3.] We made an Hole 4 Inches square in the Window-shut, which on three Sides had Ledges of Wood, A B, B C, C D, so rabbetted as to make Grooves to keep in the square flat Piece of Wood Q L, which is six Inches long, and six Inches wide; it may be drawn out, and

and ſeveral Sorts of them ſerve for ſeveral Experiments. That which we uſe in the following *Experiment* has a Hollow and a Hole in the middle behind to contain a convex Lens, which is the Object-Glaſs of a Teleſcope of 16 or 20 Foot; the round Hole in the middle mark'd *f* is above half an Inch in diameter, thro' which the Rays of the Sun paſſing through the Glaſs, enter the Room. In the fore-part alſo the Board Q is hollow'd, but not in the middle; this Hollow contains the braſs round Plate L, which towards its Circumference has an Hole at *f*, which Hole is equal to the Hole in the Board Q itſelf, and agrees with it. Together with L there is another concentric Plate, which is leſs, and moveable about the Center; this Plate has ſeveral unequal Holes, which ſucceſſively come to *f* as the Plate is turn'd round, ſo that you may at Pleaſure let the Light enter a dark Place thro' a bigger or a leſſer Hole; which in many Experiments, that are made without the Lens above-mention'd, is of good uſe. The *Pin m*, join'd with the Plate, ſerves to turn it by.

Experiment 2.] Let in a Sun-Beam thro' the Lens above-mention'd, thro' an Hole a quarter of an Inch wide, into the darken'd Room; by the Rays thus let in, at the diſtance where parallel Rays are collected, the Sun is very exactly repreſented, and its Image terminated with exactly deſcrib'd Bounds; for the Rays that come from the ſeveral Points of the Sun, which by reaſon of its immenſe diſtance may be look'd upon as parallel, are collected in one Point at that diſtance.

Plate XV. *Fig.* 2.] Now if with theſe Rays you make the Experiment above-mention'd, the ſeveral Images made by the homogeneal Rays,

ſuppoſing the Board at a juſt diſtance, are exactly terminated; and therefore the oblong Image R V, which is made of all theſe Images, is likewiſe regularly terminated.

This Experiment will ſucceed in the ſame manner, if the Rays paſs thro' a Priſm made of any Body which is denſer than Air.

Experiment 3. *Plate* XV. *Fig.* 2.] Let a triangular Priſm be made of Wood and two Glaſs Planes, and filled with Water, ſuch as is repreſented at B B (*Plate* XVII. *Fig.* 3.) If you make uſe of this Machine inſtead of the Priſm B B in this *Fig.* the Experiment will ſucceed in the ſame manner; and in paſſing thro' Water, heterogeneous Rays in the ſame manner are ſeparated by Refractions.

Experiment 4.] If any Perſon ſtanding 15 or 20 Foot off, looks at the Hole thro' which the Light is let in, it will appear round; but if before his Eyes he hold a triangular Glaſs Priſm, or the watery one mention'd in the laſt Experiment, ſo that the Rays coming from the Hole (after ſuch Refractions as the Light ſuffers in the foregoing Experiment) reach the Eyes, the Hole will appear oblong. The Situation of the Priſm will be found, if holding it horizontally with one Edge (or the refracting Angle) upwards, it be a little mov'd about its Axis, ſo as to make the Image of the Hole to aſcend and deſcend; and the Priſm be held faſt in that Poſition in which the Hole appears moſt depreſs'd.

This Experiment, as well as the foregoing ones, proves the different Refrangibility of the Rays; for by the homogeneal Rays of each Refraction, the Hole appears in the imaginary Foci of the Rays coming from the ſeveral Points of the

the Hole *, which Image is round; the Rays * 737
which undergo a different Refraction, enter the Eyes in different Directions; and you have several Images, all which form the oblong Image, which is really seen.

But that *this different Refrangibility does not de-* 855
pend upon the reflecting Medium, but the different Constitution of the Rays themselves, is prov'd; because those Rays, which in one Case undergo the greatest Refraction, are in any Refraction turn'd out of the way more than any.

Experiment 5. *Plate* XV. *Fig.* 4.] All things being dispos'd, as in the first Experiment, at any distance from the Prism B B, let the oblong Image of the Sun fall upon the vertical Prism C C, which is also moveable about its Axis; as the Rays go thro' it, let it be turn'd about its Axis, and left fix'd where the Rays are least of all turn'd out of the way by Refraction thro' the Prism; in that Case the Rays are refracted in the same manner thro' this Prism as thro' the first, but they are not dispos'd the same way, for that would form a square Image; but here the Image keeping the same Breadth, is inclin'd at R V, the Rays at V being mostly turn'd out of the way, as in the Refraction thro' the first Prism B B.

The Demonstration, before given *, *of the con-* 856
stant and settled Ratio between the Sines of the Angles * 639
of Incidence and Refraction, may be referr'd to any homogeneous Rays; but considering the different Refrangibility of the Rays, this Proportion varies, as it follows from the Experiments of this Chapter.

But *the Refrangibility in all the different Sorts of* 857
Rays is every way unchangeable, as will appear by the Experiments to be mention'd hereafter.

CHAP. XIX.

Concerning the Colours of the Rays, and their Unchangeableness.

858 *THE different Refrangibility of the Rays goes along with the different Colours; and every Sort of Rays, as they are more or less inflected by Refraction, have a particular Colour of their own, and which is wholly unchangeable.*

In respect of the Colours, the same thing is to be observ'd as has been taken notice of in regard
* 502 to other Sensations *; the Colours are Ideas
580, 6 which have nothing common with the Rays, by which they are excited; therefore we must define what we mean by colour'd Rays and colour'd Objects.

DEFINITION I.

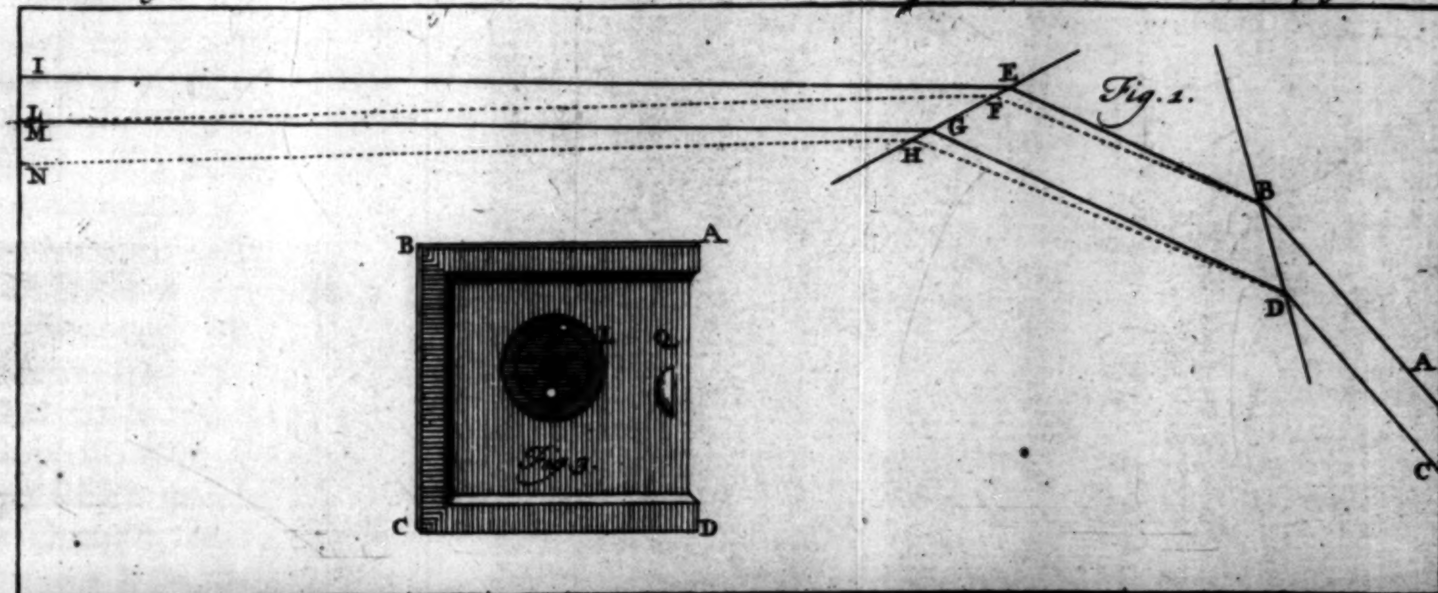
859 *An Object is said to be of such a Colour, whose Idea is excited in the Mind by the Rays reflected from the Object.*

DEFINITION II.

860 *Homogeneous Rays, which striking upon the Retina, excite in our Mind an Idea of any Colour, are called Rays of that Colour.*

We have said that the Rays excite an Idea, by which we understand that the Rays put the Fibres into a trembling Motion, and that Motion occasions an Idea in the Mind.

Plate XVI. *Fig.* 1.] It is very evident from the Experiments of the foregoing Chapter, that Rays of different Refrangibility have a different Colour; for those Experiments shew, that the Image of the Sun, which is oblong, is tinged with different



I
L
M
N
E
F
G
H
Fig. 1.
B
D
A
C
B
A
L
Q
Fig. 3.
C
D

Fig. 2.

rent Colours; *the Rays which are least turn'd out of the way by Refraction are red, the rest of the Colours are in the following Order; namely, Orange, Yellow, Green, Blue, Purple and Violet*; of which last Colours are the Rays that are most refracted. 861
The oblong Image of the Sun above-mention'd, as has been said*, is made up of an innumerable Quantity of round Images; if their Diameters be diminish'd (which is done by intercepting the Sun's Rays, so that only those that come from the Center of the Sun shall pass thro' the Prism) the Centers of the particular Images which make up the oblong Image will not be chang'd, and therefore the Length of the Image *a b* between parallel Lines is not chang'd; and this alone would remain the same, if the Breadth of the Image should be infinitely diminish'd; and therefore this Length alone is to be consider'd in determining the Limits of the Colours in the Image itself; these Colours are represented in this Figure by the Letters *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*; and the Number which is set down against each Colour, denotes the Space taken up by it in the Image, the whole Length of the Image being divided into 360 Parts.

* 853

If the Breadth of the oblong Image of the Sun be diminish'd, the heterogeneous Colours are more separated in the Image, because there are fewer particular Images confounded in the several Points, where Rays of different Refrangibilities differ little from each other. 862

The Colour of any Ray, as also its Refrangibility, cannot be chang'd by any Refractions or Reflexions, or mingling of the Rays together. 863

In this Chapter I shall speak of Reflexion and Refraction, and of the Mixture of Rays in the following one.

864 That the Refrangibility is not chang'd by Refraction, is prov'd by the 5th Experiment of the foregoing Chapter, which may alſo be referr'd to Colour, but is more clearly evinc'd by the following Experiment; concerning which it is to be obſerv'd (as may be alſo ſaid of what follows) that the Experiments are to be made with Priſms of clear Glaſs, free from Veins, for they occaſion the Light to move irregularly, and the Rays are not duly ſeparated by the Refractions.

Experiment 1. *Plate* XVI. *Fig.* 2.] Every thing being as in the firſt Experiment of the foregoing Chapter, you muſt make the Experiment with a Sun Beam going thro' an Hole of half an Inch diameter; the Frame or Stand S, in which the Priſm is, muſt be ſuch, that the little flat Board *t*, to be us'd in this Experiment, may move between its Sides; this Board has an Hole F of one 8th of an Inch Bore, thro' which the Light refracted by the Priſm is tranſmitted, whereby the Rays in the oblong Image are better ſeparated from one another, the Rays being moſtly intercepted; this oblong Image R V, at the diſtance of 10 or 12 Feet from the Priſm, falls upon the Board *t* of a Stand like the former, in which Board alſo there is a ſmall Hole F like that in the firſt, thro' this the Rays paſs upon a ſecond Priſm laid upon this Stand, and are refracted in the ſame manner as in the firſt; by moving the firſt Priſm a little about its Axis, the Image R V aſcends or deſcends, whereby the different Rays are ſucceſſively tranſmitted thro' the Hole; in every Caſe, the Rays refracted thro' the ſecond Priſm, and ſtriking upon the flat Board T, which is cover'd with white Paper, are not diſpers'd at H; but the Image is round, if the Rays fall perpendicularly upon the Paper, and alſo of the ſame Colour as the Rays

falling

falling upon the second Prism; yet the Image H is so much the more lifted up, as the Rays by Refraction thro' the first Prism are more turn'd out of the way; that is, those that are most refrangible in the one Case, do also suffer the greatest Refraction in the other.

It will appear also by the following Experiments, that the Refrangibility and Colour are not chang'd by Reflexion. 865

Experiment 2.] The Rays which, for Example, make the red Part of the oblong colour'd Image, whatever Body they are reflected from, are always red; that is, all Bodies appear red in that Light; in the Violet Light they are Violet; Green in the Green; and so on in other Colours.

This will appear by trying it with Vermillion, Orpiment, blue Bice, or Cloth of any Colour, *&c.*

Experiment 3. *Plate* XVI. *Fig.* 3.] Let the Light enter the dark Room thro' two Holes of a quarter of an Inch diameter each, in the round Plate moveable in the Window; let these Beams be about two Inches asunder, and reflected by the plane Mirror S.

The Plate and Mirror must be so dispos'd, that the two Beams may fall upon two Prisms A A, which are laid horizontally upon the same Frame, so that the oblong Image, produc'd by the Refraction of those Prisms, may touch one another at their Sides; let one Prism be turn'd a little about its Axis, that the Red of one Image may be just on the side of the Violet of the other; let these Colours, and none of the rest, be intercepted by a wooden Ruler that has a white Paper pasted upon it, so that the Red be at R;

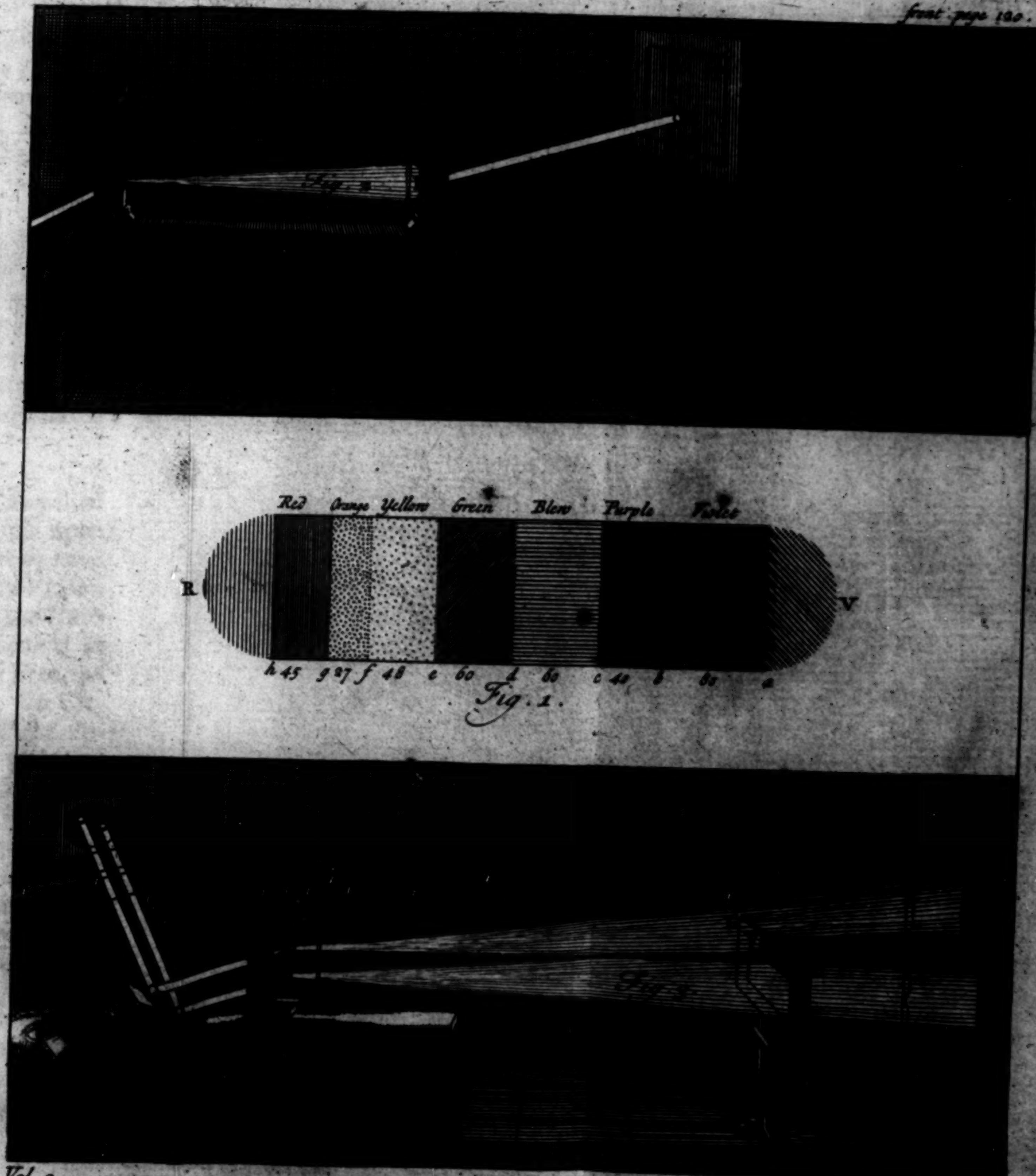
 and

and the Violet at V, the rest of each Image falling upon the Wall, which must be cover'd with a black Cloth. If any Person stand at O, and thro' the Prism B B looks at those Colours R and V (in the manner describ'd concerning the Hole in *Experiment* 4. of the foregoing Chapter) he will see the Colours separated from one another, the Red at *r*, and the Violet at *v*; which therefore being reflected in going thro' the Prism B B, undergoes a greater Refraction.

In the first Experiment of this Chapter we gave a Method, whereby to separate the heterogeneous
866 Rays better than in other Experiments; in the following Experiments, Lights of divers Colours become much more homogeneous, which is requir'd in the sixth Experiment of this Chapter.

Experiment 4. *Plate* XVII. *Fig.* 1.] Let the Sun's Light enter the dark Room thro' an Hole of one 8th of an Inch, the Sun Beam must be reflected by the Prism A A to the convex Lens V, which stands upon a Foot, and is about 3 or 4 Inches wide; the Length of the incident and reflected Rays taken together is about 7 Feet; the Convexity of the Lens is such, that the Foci of the Rays coming from the several Parts of the Hole, at the distance of 10 or 12 Feet from the Lens, will form the Representation of the Hole,
* 711 if a Paper be held there*. Just beyond the Lens place the Prism B B, whereby the Rays (as in the first Experiment of the foregoing Chapter) are dispers'd; now placing the flat Board T at the distance at which the Rays coming from the several Points are collected, there will fall upon it a well terminated oblong colour'd Image R V, whose Length will have a greater Proportion to its Breadth than in other Experiments, and which therefore

Plate 16.


Red
Orange
Yellow
Green
Blew
Purple
Violet
R
V
h 45 g 27 f 48 e 60 d 60 c 40 b 80 a
Fig. 1.

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4 AP 64
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therefore is made up of Rays more homogeneous*, and so much the less mix'd as the Hole in the Window is the less; by moving forward or backward the Board T, one may find the Distance at which the Image is most distinct and terminated without the Penumbra. * 862

Now that the Rays separated in this Experiment are homogeneous enough, is prov'd from this, that they can be no more dispers'd by a new Refraction; and that this is the Property of homogeneous Rays, follows from their equal Refrangibility, which has been already confirm'd by an Experiment*, and is more fully demonstrated by the following one. * 864

Experiment 6.] Take two Circles of Paper of an Inch diameter each, and let Light fall upon them in such a manner, that the one may have the homogeneous Rays of any Colour fall upon it, and the other may be enlighten'd by the Rays of the Sun; if both these Papers be look'd at thro' the Prism at the distance of some Feet, as in the third Experiment of this Chapter, the Circle enlighten'd by the heterogeneous Light appears oblong, and ting'd with different Colours, as in the fourth Experiment of the foregoing Chapter; but neither the Colour nor Figure of the other Circle is chang'd.

Experiment 6.] Upon a white Paper draw black Lines parallel to one another, and about the 16th Part of an Inch wide; let these be enlightened, by throwing upon the Paper the oblong Image, which is describ'd in the fourth Experiment, so that the Lines may lie long-wise in the Image; besides this, you must have a convex Lens, about 5 or 6 Inches wide, sustain'd upon a Foot, such

as

as are represented at V (*Plate* XIX. *Fig.* 2.) which collects the red Rays that come from a radiant Point six Foot distant from the Glass, at an equal distance on the other side. If this Lens be plac'd at the distance of six Feet from the Image above-mention'd, the Parts of the black Lines that are enlighten'd by the Red falling upon the Paper, by means of the Rays which are collected by the Lens, will be exactly represented in the red Image at the distance of six Feet; but you must bring the Paper forward about 3 Inches and a half, to make those Parts in the Lines which are enlightened by the Purple, to appear distinct in that Part of the Image which is of the same Colour. The intermediate Colours give Images at intermediate Distances; the Violet is so weak, that the Threads cannot be represented in it.

This Experiment does also confirm, that the Colour of reflected Rays is not chang'd by a new Refraction thro' the Lens; as also that the most refrangible Rays are more inflected than the others in passing thro' the Lens.

867 This last Experiment does also prove, *that the different Refrangibility of the Rays is the Cause that hinders the Perfection of Telescopes*; for the Foci of the Points that are equally distant, fall at different Distances from the Lens, according to their different Colours; whence all the Representations of the Points are unequally distant from the Eye-Glass, and therefore they cannot be all perfectly seen thro' it.

868 Concerning the Reflexion of the Rays, it is to be observ'd, that *those Rays are more easily reflected totally which have the greatest Refrangibility*; for the greater is the Refraction of the Rays, the less Obliquity

Obliquity is required to make them be totally reflected *. * 793

Experiment 7.] Take a Prism, plac'd as before *, in the Experiment where it was observ'd, * 790
that by moving the Prism about its Axis, the Rays that first went thro', when their Inclination is increas'd, become wholly reflected; but if the Prism be gently mov'd in this Case, we shall perceive that the Violet Rays are the first which will be wholly reflected, then the Purple Rays, and all the rest in the same Order as they are in the oblong Image of the Sun so often mention'd; which appears if the reflected Rays be separated by the Refraction of the Prism.

CHAP. XX.

Of the Mixture of Colours, where we shall speak of Whiteness.

THat the Refrangibility and Colour of the 869
Rays are not chang'd by the Mixture of Rays of different Refrangibility, has already been said *, and now we must prove it by Experiments. * 863

Experiment 1. *Plate* XVI. *Fig.* 3.] This Experiment must be made in the same manner as the third of the foregoing Chapter; here you must make the Red R, and the Violet V be confounded and mix'd together, by throwing them upon the same Part of the Ruler L L, which thereby will appear of a Purple Colour in that Place; but if a Person looks at them thro' a Prism, the Colours will appear separated; and therefore neither the Colour nor Refrangibility are chang'd by this Confusion of Colours.

Expe-

Experiment 2. *Plate* XVII. *Fig.* 2.] If the oblong colour'd Image of the Sun (of which mention was made in the first Experiment of the 18th Chap.) falls at R V upon the convex Lens L, mention'd in *Experiment* 4. of the foregoing *Chap.* which must be plac'd at 6 or 7 Foot from the Prism BB, the divergent Rays will converge by the Refraction of the Lens, and intersect one another at the distance of 9 or 10 Feet at A; if the Board T be plac'd at a greater distance, the Rays, which diverge again after the Intersection, will fall upon it dispers'd, and you will again have an oblong colour'd Image; but the Colours, by reason of the Intersection at A, will appear in a contrary Order, and will not be chang'd by having been mix'd together at A.

Experiment 3. *Plate* XVII. *Fig.* 2.] Every thing still remaining as in the former Experiment, if with a black Paper you intercept some of the Rays of the Image R V, which changes the Mixture (which this way may be vary'd in any manner) the Colours of the other Rays, that are again separated, are no way chang'd.

870 *If the Rays of the Sun*, as they come to us, *are wholly reflected by any Body, that Body appears white*; but these Rays are an Heap, or Parcel of
* 847 Rays of various Colours*; whence we deduce,
858 that *a Mixture of different Colours makes a White-*
871 *ness*; for if the Colours which are observ'd in the oblong Image of the Sun, so often mention'd, be mix'd and confounded together, in the same Proportion as they are in that Image, a Whiteness will be produc'd; which also proves, that in that respect the Rays are unchangeable: the Rays that come from the Sun appear white; but if they are separated, their Colours are discover'd; and if they

they be mix'd again, the Whiteneſs will be reſtored.

Experiment 4. *Plate* XVII. *Fig.* 2.] Things being diſpos'd as in the two foregoing Experiments, let the Board T be plac'd at A, in the very Place where all the Rays of the Image R V are confounded together, there will be a Whiteneſs at A; if with a black Paper you intercept the Red of the Image R V, the White will vaniſh, and the Colour at A be bluiſh; but if you intercept the violet and blue Rays, the White becomes reddiſh.

Experiment 5. *Plate* XVII. *Fig.* 3.] Take three triangular Priſms, made of Wood and Plates of Glaſs which contain Water, as B B, D D, D D; the Plates of Glaſs in each of them make an Angle of about 70 Degrees; the Length of the Plate is of 6 or 7 Inches, and their Breadth of 3 Inches; theſe Plates are fix'd in another manner in the Priſms D D, D D, than in the Priſm B B, ſo as to make their Baſes bigger; that is, theſe Priſms are ſhorter and deeper than the other. Let the Sun's Rays be refracted thro' the Priſm B B, as in *Experiment* 3. of *Chap.* 18. and let the oblong Image of the Sun at the diſtance of 3 or 4 Foot fall upon the Surface of the Priſm D D, plac'd parallel to the Surface of the Priſm B B, out of which the Rays go. In the ſecond Priſm the Rays undergo a contrary Refraction than in the firſt, becauſe of the Paralleliſm above-mention'd; and becauſe the Edge of the Angle, form'd by the Glaſs Plates in the Priſm B B, is turn'd upwards, and that of D D downwards; therefore the firſt Refraction is deſtroy'd by the ſecond, and the Rays go out of the Priſm D D parallel to one another, and fall upon R V; for if the Priſms be brought together, ſo that the parallel Surfaces may

may touch one another, the Light will paſs thro' a Medium terminated with parallel Planes (which is form'd by the two Priſms join'd together) thro' which Light, of any degree of Refrangibility,
* 628 will paſs without change of Direction *. Now the Priſms are ſeparated, that the heterogeneous Rays may be ſeparated before they again become parallel; if theſe colour'd Rays fall upon the third Priſm D D, and in paſſing thro' it undergo a Refraction like that which they have undergone in paſſing thro' the firſt or ſecond Priſm, the Rays that go out at *r v* converge, on account of unequal Refractions in Rays of different Colours, and concur at A, in which Place alſo Whiteneſs will be produc'd, as in the foregoing Experiment.

Experiment 6.] If an oblong colour'd Image of the Sun be made after the manner deſcrib'd in *Experiment* 1. *Chap.* 18. and a Perſon ſtanding at the diſtance of the Priſm that refracts the Light, looks at the Image thro' the ſaid Priſm, as was done in reſpect of the Hole in the fourth Experiment of the ſame Chapter, he will ſee a round and white Image, the ſecond Refraction deſtroying the firſt; for thereby the Rays being again mixed, enter the Eye, and in this Caſe make the Object appear white.

872 *The Mixture of all the Colours which are obſerv'd in the oblong Image of the Sun is not neceſſary for producing White*; the Whiteneſs of the Sun's Rays is a little inclin'd to yellow; and therefore if part of the yellow Rays be taken out of the Mixture, the White will be the more perfect. From the Mixture of four or five Colours in a juſt Proportion White will be produc'd.

Primary,

Primary, that is, homogeneous, *Colours being mix'd, produce innumerable Colours, different from the primary or homogeneous ones.* From a Mixture of other Colours one may produce a Colour like that which is homogeneous; but *when there can be no difference observ'd by the naked Eye between an homogeneous and a mix'd Colour, one may perceive a sensible difference thro' a Prism.* 873

Experiment 7.] Thro' a Prism look at any small Objects, such as Letters upon Paper, Flies, and other such things; if they be expos'd to the common open Light, they will appear confus'd; but if they be enlighten'd by the homogeneous Light of the fourth Experiment of this Chapter, they will appear distinct when seen thro' the Prism. 874

CHAP. XXI.

Of the Rainbow.

HAving made an end of considering what relates to the Rays, whereby Bodies are enlighten'd; before we leave this Subject, we must explain a Phænomenon, which is too remarkable and common to be past by in Silence.

The *Iris* or *Rainbow* is what every Body has often seen; we must explain what is the Cause of it, having first laid down some things for that Purpose.

Plate XVIII. *Fig.* 1.] *Let there be a dense Medium encompass'd with a rarer, terminated by the Circle* BDFH; *let homogeneous Rays that are parallel to one another fall upon it*, and let AB be one of these Rays; let the Semidiameter CB be drawn and continu'd to N, it will be perpendicular to the 875

the Surface separating the Mediums; A B N
therefore is the Angle of Incidence; this Angle
is equal to the opposite vertical Angle C B L,
whose Sine is C L, perpendicular to B L, and
going thro' the Center; the Ray is refracted to-
* 624 wards the Perpendicular *, and C B M is the An-
gle of Refraction, whose Sine is C M drawn from
C perpendicular to B D: there is the same Pro-
* 639 portion between such Lines as C L and C M *, for
every Ray, as there is for A B. The Ray B D
does in part penetrate into the rarer Medium in
the Direction D E, and is in part reflected along
D F, and makes the Angle of Reflexion C D F
* 805 equal to the Angle of Incidence * B D C; whence
B D and D F are equal. The Ray D F does also
in part go out of the denser Medium along F G,
and is in part reflected along F H; which in the
same manner does in part go thro' H I, and is in
part reflected: But this Reflexion, and other
farther Reflexions and Refractions, we shall not
consider; they are too weak, on account of the
several Divisions that the Light has undergone.

Plate XVIII. *Fig.* 1.] The Ray F G, which after one Reflexion goes out of a denser Medium, makes the Angle G P A with the incident Ray A B, which varies in different incident Rays; therefore tho' these Rays should be parallel, *they will be scatter'd when they go out, after one Reflexion*, as may be seen by the second Figure.

The Ray E E, which being continu'd goes
thro' the Center C, is not turn'd out of its way
* 806 either by Reflexion or Refraction *.
629 As you recede from this Ray, the returning
Ray is continually less and less inclin'd to the in-
cident one. So the Ray D D, which goes out
of a denser Medium along *d d*, and returns a-
long the Line, makes a greater Angle with *d d*,
than

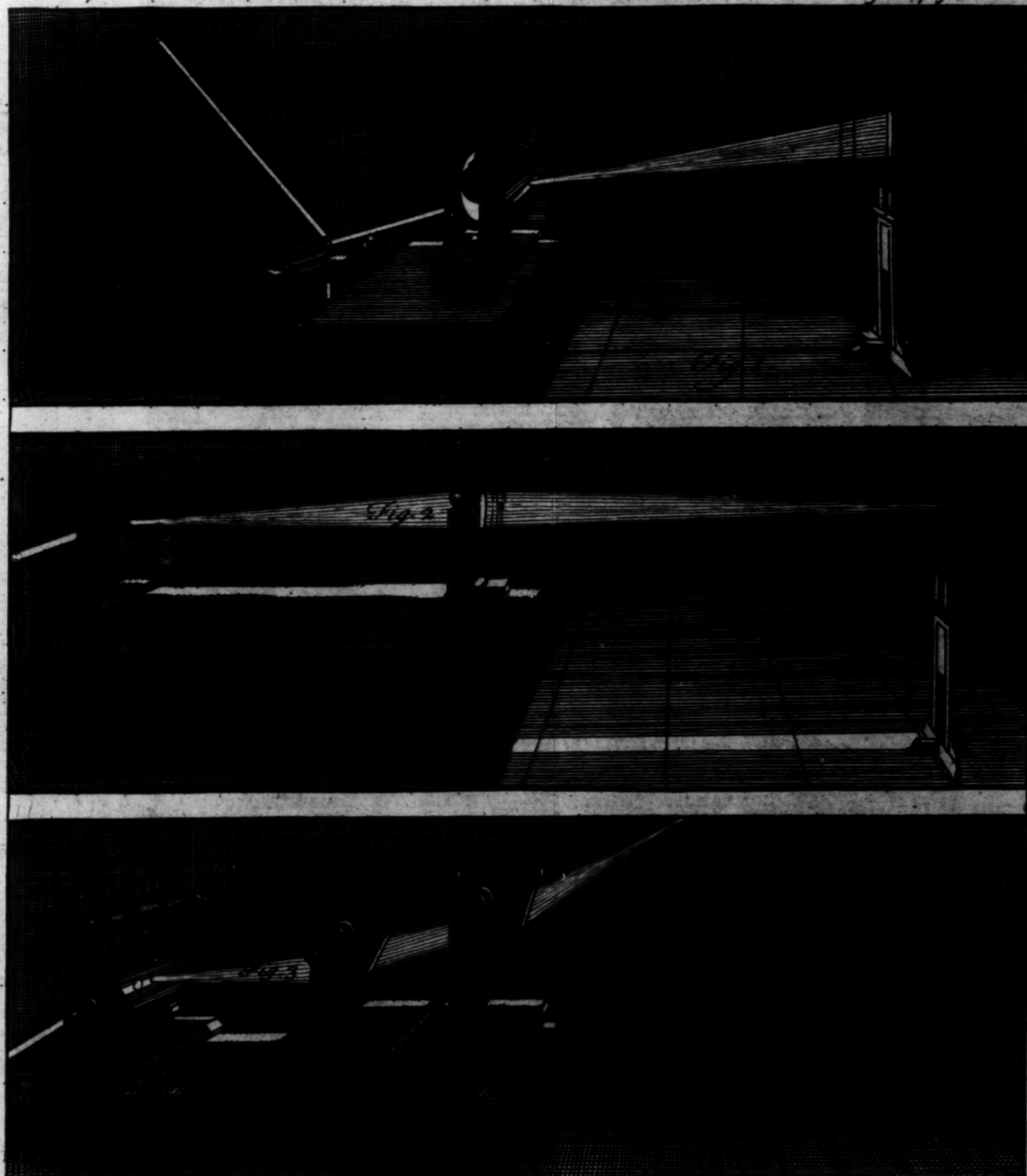


Fig. 2

than the intermediate Rays between DD and EE do make with their returning Rays, which go out of the denſer Medium.

Let BB be a Ray, in reſpect of which this Inclination is the leaſt of all, that is, which makes the Angle GPA (*Fig.* 1.) the biggeſt of all. Beyond BB the returning Rays are more inclin'd to the incident ones; thus AA returns along *a a*. 876

From this Diſperſion *of the returning Rays* receding from the denſer Medium, they become continually weaker and weaker, and their *Colour cannot be perceived throughout the whole Space which they fill*, tho' the Colour of the incident Rays be vivid. *The Colour* in the returning Rays *is only ſenſible, where the neighbouring Rays are parallel*, and thoſe next to them diverge out very little; ſo that at a great Diſtance they are denſe enough to be perceiv'd. *Theſe only are ſaid to be efficacious*, and will be ſuch, when the incident Rays which are near one another, being refracted, concur in the very Point of Reflexion. 877

Plate XVIII. *Fig.* 3.] Let AB, *a b*, be neighbouring Rays parallel to one another, falling upon a circular Surface that terminates a denſer Medium; if theſe being refracted along BD, *bd*, do concur in D the Point of Reflexion, the reflected ones DF, D*f*, will make the ſame Angles with one another as the incident ones DB, D*b*; therefore the refracted Rays FG, *f g*, will be parallel * and efficacious *. In this Caſe the following Method will ſerve to determine the Angle made by the incident Ray with the returning one; that is, the Angle APG, which here is the greateſt of all. *627 *877

Let us call the *Ratio* of I to R, that which is found between the Sines of the Angle of Incidence and Refraction, when the Light goes 878

 out

out of a rarer Medium, by which a denser is encompass'd, into a denser contain'd in the Circle itself; therefore having drawn C*m* perpendicular to *b* D, and the Arc *mn* with the Center C and Semidiameter C*m*,

I, R :: CL, CM :: C*l*, C*m* :: CL − C*l* = L*l*, CM − C*m* = M*n*.

Draw B*o* perpendicular to BL, and also B*p* perpendicular to BD; and draw *bp*, so that it may make a right Angle with B*p*; lastly, join together by Lines the Points B, C, and M, *m*, the Triangles B*bo*, BCL are similar; for they are rectangular, and the Angles *o*B*b* and CBL (the difference of each of which from a right Angle is the Angle *o*BC) are equal.

It may be prov'd in the same manner, that the Triangle BMC and B*bp* are similar; the Triangle M*mn*, which is rectangular at *n*, is also similar to this; for the Sides M*n* B*p*, which are perpendicular to the Line BD, are parallel; as also M*m* and B*b*, because the Lines BD, *b*D, are bisected at M and *m* into equal Parts; therefore also B*b* is the Double of M*m*, and B*p* the Double of *mn*.

Hence we deduce

BC, BL :: B*b*, B*o*.

BC, BM :: B*b*, B*p*.

Therefore

BL, BM :: B*o* = L*l*, B*p* = 2 M*n* :: I, 2 R :: CL, 2 CM, by comparing these Proportions with the aforesaid Proportion.

Now since the Squares of proportional Quantities are themselves proportional, you will have

$BL^q, CL^q :: BM^q, 4CM^q.$

Whence we deduce

$BL^q + CL^q :: BC^q, BL^q :: BM^q + 4CM^q = BC^q + 3CM^q, BM^q = BC^q - CM^q = BL \times LC^q - CM^q.$

By

By subtracting the first and second Term from the third and fourth (which does not change the Proportion) you will have

$BC^q, BL^q, :: 3\,CM^q, LC^q - CM^q, :: 3\,R^q, I^q - R^q$; for there is the same Ratio between C M and L C as between R and I.

If therefore you know the Ratio between R and I, you have the Ratio between the Semidiameter B C, and the Line B L, which is the Sine of the Angle B C L, which Angle therefore is given, and by consequence you have the Arc B N, and also F G, for they are equal.

Having the Sine B L, you have also the Sine of the Angle B C M; because (as we have shewn before)

$$BL, BM :: I, 2R.$$

Therefore the Arc B D is determin'd, to which D F is equal.

Hence we may easily find the Arcs N H and B F; if the former be taken out of the latter, 879
and the Remainder be divided into two equal Parts, we shall have, as is well known, the Measure of the Angle A P G.

When the Ratio between I and R varies, the Angle A P G is chang'd, which therefore becomes different, according to the different Refrangibility of the Rays.

If the abovesaid Surface be enlighten'd by heterogeneous Rays, as they flow from the Sun, *the efficacious Rays of different Colours do not make equal Angles with the incident ones, and* so *by the help of this Refraction the Colours are separated.* 880

Plate XVIII. *Fig.* 4. *Experiment* 1.] Let the Sun's Light enter the dark Chamber thro' a Slit in the moveable round Plate O, and being horizontally reflected from the Looking-glass S, let it pass thro' a Slit in the little Board or Stand T;

* 630 as has been before explain'd.* Take a Phial exactly cylindric, made of clear Glass, and full of Water; let the Beam or Ray at *f g* fall upon the Surface of the Phial, it will be refracted in the Water towards *h i*, and there reflected, and will go out of the Phial at *l m*; the Phial may be easily so plac'd as to make these Rays efficacious; and because of the Breadth of the incident Ray or Beam, efficacious Rays of all Colours will go out of the Phial in the same time, for they are very little distant from one another in their Incidence; if these efficacious Rays fall upon a white Paper, at the distance of four or five Feet from the Phial, they will produce vertical *Fasciæ* or Pillars, of various homogeneous Colours, arising from the efficacious Rays of each Colour; if also the Eye be plac'd any where at the distance of some Feet from the Phial, as at N, in these efficacious Rays, it will see in the Phial that Colour whose Rays enter the Eye, and by a successive Motion of the Eye it will perceive all the afore-mention'd Co-
* 861 lours.*

881 *Plate* XVIII. *Fig.* 5.] But as to those Rays, which after a double Refraction in a denser Medium emerge, they will be efficacious if they are parallel after the first Reflexion; for then F H, *f h*, are in the same manner inclin'd to H *h* as B D, *b d*, to B *b*; and therefore supposing the incident Rays A B, *a b*, to be parallel, the emerging Rays
* 927 H I, *h i*, will also be parallel*.

In this Case *d* D is half of the difference between the Arcs D E and *d f*, or D B and *d b*, but their difference is B *b*—D *d*; if therefore this last be subtracted from the other, there will remain the Double of the Arc D *d*, whose Triple therefore is B *b*. If by Lines the Points D, *d*, and B, *b*, be join'd, the Triangles B E *b* and D E *d* will be similar, as is known; which therefore obtains, tho'

tho' the Arcs B *b*, D *d*, be so very small, that they may be taken for right Lines.

There is therefore that Ratio between E D and E *b*, which obtains between these Arcs, that is, E D is the third Part of E *b*, or E B; because we suppose the Arc B *b* to be extremely small. M D therefore is divided into two equal Parts at E; and M E is a third Part of E B.

Now if (as in *Fig.* 3.) the Triangles B *o b*, B *p b*, and M *m n*, be form'd, M *m* will be the third Part of B *b*, and B *p* the Triple of M *n*; now if, *mutatis mutandis*, we apply to this Figure what was demonstrated with respect to *Fig.* 3. * * 878
because in this B *p* is equal to 3 M *n*, whose Square is 9 M *n*q, we shall have

$$BC^q,\ BL^q :: 8R^q,\ I^q - R^q.$$

From which Proportion, as was said of *Fig.* 3. the Arc B N may be discover'd to which H G is equal; and because in this Case

$$BL,\ BM :: I,\ 3R,$$

You have also the Arc B D, to which (because the Angles of Reflexion are equal to the Angles of Incidence) * D F and F H are equal. * 805

From which things being found, we may easily deduce the Arcs G F D N, and B H, whose half Difference is the Measure of the Angle H P B, which is form'd by the emerging Ray with the incident one; which Angle in this Case is the least of all that are like it, and is different according to the different Refrangibility of the Rays; 882
whence also in this Case the *efficacious Rays of various Colours, supposing the incident ones parallel, are separated after a double Reflexion.* 883

Plate XVIII. *Fig.* 4. *Experiment* 2.] This Experiment is perform'd after the same manner as the former, only the Situation of the Phial must be a little chang'd, that after two Reflexions in

 the

the Phial, the Rays may come to the Eye or Paper towards N.

884 What has been hitherto explain'd, may be applied *to the Rainbow*; for which Phænomenon *it is required, that Drops of Water ſhould be ſuſpended in the Air; that the Spectator ſhould be placed with his Back towards the Sun, between it and the Drops; and that there ſhould be a dark Cloud behind the Drops*, that the Colours may be more ſenſible, which are ſcarcely perceiv'd if vivid Light enters the Eye at the ſame time.

If, theſe things being ſuppos'd, we conceive each Drop to be cut by Planes paſſing thro' the Sun and the Eye of the Spectator, what has been demonſtrated of a Medium terminated with a circular Surface, * may be applied to each of theſe
* 878, 879, 880, 881, 882, 883.
Sections.

Now here we ſpeak of Rays that penetrate out of Air into Water. In red Rays, that is, thoſe which are leaſt of all refrangible, the *Ratio* between the Sine of the Angle of Incidence and the Sine of the Angle of Refraction, that is, between I and R, is that of 108 to 81; or which is the ſame, of 4 to 3; with which Numbers if the Computation be made, the Angle A P G (*Fig.* 3.) will be 42 Deg. 2 Min.*, and the Angle A P I (*Fig.* 4.) will be 50 Deg. 57 Min.* If we ſpeak of the Violet Rays, I and R are to one another as 109 to 81; which Numbers give the Angles A P G (*Fig.* 3.) of 40 Deg. 17 Min.*, and A P I (*Fig.* 4.) of 54 Deg. 7 Min.*

* 879
* 882
* 879
* 882

Plate XIX. *Fig.* 1.] Let the Drops be ſuppos'd to be diffus'd in the Air, and enlighten'd by the Sun's Rays, which are parallel to one another, and to the Line O F, that paſſes thro' the Eye of the Spectator. Let the Lines *e* O, E O, *b* O, B O, be conceiv'd to be drawn; and let the Quantity

of

of the following Angles be thus, (*viz.*) *e* O F of 40 Deg. 17 Min. E O F 42 Deg. 2 Min. *b* O F 50 Deg. 57 Min. B O F 54 Deg. 7 Min. These same Lines, with the incident Rays *de*, D E, *a b*, A B, form Angles that are respectively equal to the afore-mention'd; therefore if the Drops be conceiv'd at *e*, E, *b*, B, the Violet efficacious Rays, after one Reflexion in the Drop *e*, enter the Eye, and the red efficacious Rays come to the Eye from the Drop E; in like manner, after one Reflexion the other intermediate Colours are observ'd between *e* and E in the above-mention'd Order *. After two Reflexions in the Drop, the * 861
efficacious red Rays come to the Eye from the Drop *b*; and the efficacious Violet ones from the Drop B; the intermediate Colours appear between these Drops after the same manner as between E, *e*; but they are dispos'd in a contrary Order, and by reason of their double Reflexion are also weaker.

Let us conceive a Line at O *e* to be revolv'd about a fixed Line O F, preserving the Angle *e* O F, and to form a Cone, or part of a conic Surface; in every Situation the Line *e* O will, with the Rays of the Sun that are parallel to one another, and to the Line O F, form an Angle of 40 Deg. 17 Min. *If* therefore *the Drops be dif-* 885
fus'd near part of the Surface of this Cone, at the same or different Distances, *the Eye will see a* Violet Arc or Bow. The same may be said of the other Colours; and therefore Drops being suspended in the Air, it sees an Arc or *Bow* of the Breadth *e* E, *ting'd with the homogeneous Colours* before mention'd *, that are dispos'd in the same * 861
Order as in the Experiments with Prisms; because the heterogeneous Rays are separated as much in the Drops as in the Prism *. * 852
880

886 By the same way of reasoning it is plain *there will be a broader* Arc or *Bow surrounding the first, in which the same Colours will appear in a contrary Order, and weaker.*

Experiment 3.] Hang up a black Cloth in the Light of the Sun, and let a Spectator look at it standing between the Sun and the Cloth; then if Water be made to fall in small Drops between the Spectator and the Cloth, the Spectator will see a Rainbow, at least the inner one.

CHAP. XXII.

Of the Colours of thin Plates.

WE pass on to the Colours of natural Bodies; and before we go any farther, we think it proper to examine thin Plates. Whoever attentively has observ'd very thin Glass, or Bubbles made of Water thicken'd with Soap, must have perceiv'd several Colours in them. Rays of Light, by help of a thin transparent Plate, are
887 separated from one another, and *according to the different thickness of the Plate, the Rays of some Colours are transmitted, and those of others are reflected; and the same very thin Plate is of another Colour, when seen by the transmitted Rays, than when seen by the reflected ones.*

Experiment 1. *Plate* XVIII. *Fig.* 6.] Take two Object-Glasses belonging to long Telescopes, A B and C D, and let one of them be laid upon the other; then let them be press'd together hard, and in the middle, where the Glasses touch one another, you will see a transparent Spot, which is encompass'd with colour'd Circles. If the Light

Light reflected by the Air that is between the Glasses comes to the Eye at O, there will appear a black Spot; and the Colours, which, as you recede from the Center, are so disposed, that by reason of the same Colours coming over again, they may be referr'd to several Orders, will be as follows: BLACK, Blue, White, Yellow, Red: VIOLET, Blue, Green, Yellow, Red: PURPLE, Blue, Green, Yellow, Red: GREEN, Red; which Colours are all encompass'd with other Colours; but as you recede from the Center, grow continually weaker and weaker.

If the Light passes thro' the Glass to the Eye at O, the transparent Spot which transmits all the Rays is white; and by that Series, as you recede from the Center, there will appear Colours, which are also referr'd to several Orders contrary to those above-mention'd: WHITE, yellowish Red, Black, Violet, Blue: WHITE, Yellow, Red, Violet, Blue: GREEN, Yellow, Red, bluish Green: RED, bluish Green, which are also encompass'd with weaker Colours.

Experiment 2.] Blow up Soap'd-water into a Bubble, to form a thin Plate of Water; let this be cover'd with a very clear Glass, lest by the Agitation of the Air the Colours to be observ'd in that Bubble should be confounded by the Motion of the Water; such a Bubble, because the Water continually runs down every way, is very thin at top, and the thickness in going down is continually increas'd; and for the same reason the thickness of the whole is continually diminish'd; before the Bubble breaks, the top of it becomes so thin as to transmit the whole Light, and appear black; if in that Case the Bubble be observ'd by reflected Light, when it is enlighten'd

en'd by the Reflexion of a whitiſh Sky, and the extraneous Light is intercepted by placing any black Body behind the Bubble, the black Spot above-mention'd will appear, and be encompaſs'd with the ſame colour'd Circles, diſpoſed in the ſame Order as about the black Spot in the former Experiment; as the Water deſcends, the Rings are continually dilated till the Bubble burſts.

When the extreme Circumference of the Bubble appears red by the reflected Rays, if it be look'd at ſo as to be ſeen by the tranſmitted Rays, it will appear blue; and generally the Colours produc'd by tranſmitted and reflected Rays, in the ſame manner as in the foregoing Experiment, are oppoſite to one another.

888 By comparing theſe Experiments, it follows, that *if we increaſe the thickneſs of a very thin Plate, its Colour will be chang'd, and there will be the ſame Changes ſucceſſively, and in the ſame Order, whether the Plate be form'd out of a rarer or a denſer Medium*; for in the Plate of Air, between the Glaſſes, and the watery one in the Bubble, whoſe thickneſs increaſes as it goes farther from the middle, the Colours will be in the ſame Order; yet *in a*
889 *denſer Plate a leſs thickneſs is requir'd than in a rarer to have it ting'd with the ſame Colour.*

Experiment 3.] Every thing being diſpoſed as in Experiment 1. if you wet the Edges of the Glaſſes a little on one ſide, the Water will by degrees inſinuate itſelf between the Glaſſes, and there will be obſerv'd the ſame colour'd Circles as in the Air, neither will their Order be chang'd, but the Circles will be leſs; when the Water is got as far as the Center, all the Portions of the Circles in the Water will be ſeparated from the Portions of the Circles in the Air, and be all reduc'd into a leſs Space.

The

The Colour of a Plate depends upon its Thickness * 890
and Density, and not upon the encompassing Medium. * 887
* 889

Experiment 4.] If you take a Piece of Ising-glass or Talk, so thin as to have it colour'd, the Colours will not be chang'd by wetting it; that is, if instead of Air the Plate is encompass'd with Water.

The Colour of the same Plate is so much the more 891
vivid, as its Density differs more from the Density of the circumambient Medium. This is prov'd by the foregoing Experiment, in which the Colours of the Plate, when wet, are more languid than those of the same Plate encompass'd with Air. In the third Experiment also the Colours are less vivid than in the second; in both there is a Plate of Water; but in the second Experiment it is inclosed with Air, and in the other with Glass; but Water and Glass differ less in Density than Air and Water.

If Mediums equally differ in Density, the Colours 892
will be more vivid if the denser be encompass'd with the rarer; for a very thin Glass Plate, which is colour'd on account of its thinness, being encompass'd with Air, the Colours will be more vivid than in *Experiment* 1. in which a Plate of Air is encompass'd with Glass.

A Plate of the same Density, encompass'd with the 893
same Medium, will reflect so much the more Light as
it is thinner; *yet if the thickness be too much dimi-* 894
nish'd, it does not reflect the Light. All this is plain from the foregoing Experiments; in the three first, the colour'd Circles, which are the least, and which are also the thinnest, reflect Light best of any; but in the Center, where the Spot is the thinnest of all, there is no sensible Reflexion; as this clearly appears in the second. In the first there is also a very thin Plate of Air, which does not

not reflect Light; for the transparent Spot in the Center is much bigger than those Parts of the Surfaces of the Glasses, which immediately touch by the yielding inwards of the compress'd Parts.

895 *If there are Plates of the same Medium, whose Thicknesses are in an arithmetical Progression of* the natural Numbers 1, 2, 3, 4, 5, 6, 7, *&c. if the thinnest of them all reflects any homogeneous Rays, the second will transmit the same*, the third again will reflect them, *and the Rays will be alternately reflected and transmitted*; that is, the Plates whose Thicknesses in the above-mention'd Progression answer to the odd Numbers 1, 3, 5, 7, *&c.* reflect the Rays which the others transmit, whose Thicknesses answer to the even Numbers 2, 4, 6, 8, *&c.*

This Property of the Plates obtains in respect of any Sort of homogeneous Rays, with this difference, that different Thicknesses are required

* 887 for different Colours, as has been said before*; the thinnest of all for reflecting Violet, and they must be the thickest for reflecting Red; if the Thicknesses are intermediate, the Rays of an intermediate Refrangibility are reflected; that is,

896 *as the Refrangibility of the Ray increases, the Thickness of the Plate that reflects it is diminish'd.*

Experiment 5.] Let the Experiment be made in a dark Room to produce the oblong Image of the Sun upon a Paper, such as is mention'd in *Experiment* 1. *Chap.* 18. Take two Object-glasses of long Telescopes (such as were mention'd in the first Experiment of this Chapter) let them be press'd together, and so disposed, that every single Colour of the Image above-mention'd may be successively seen in them as in a Looking-glass; that is, that the Glasses may be successively enlighten'd by several homogeneous Rays; which

may

may be done by gently moving about its Axis the Prism that separates the Rays to make the oblong Image. The Rings mention'd in the first Experiment appear, but more in Number, and only of one Colour, by reason of the Unchangeableness in homogeneous Rays*; in the Interstices of those Rings the Rays are transmitted, as plainly appears by holding a Paper behind, upon which the transmitted Rays will come; the Rings are least of any when they are violet, then are successively dilated, considering the following Colours, quite to the Red; the Rings being of any Colour, if you measure exactly the Diameters of the Circles that may be conceiv'd to be in the middle of the Breadth of the Rings, the Squares of their Diameters will be to one another as the odd Numbers 1, 3, 5, &c. and measuring in the same manner the Diameters of the Circles in the middle of every one of the Interstices between the Rings, the Squares of their Diameters will be as the even Numbers 2, 4, 6, &c. Now in using spherical Glasses, the Thicknesses of the Plate of Air in the Circle above-mention'd are as the even and odd Numbers.

* 863

DEFINITION.

An homogeneous Colour, in a Plate of any Medium, is said to be of the first Order, *if the Plate be the thinnest of all those that reflect that Colour; in a Plate whose thickness is triple, it is said to be* of the second Order, &c. 897

A Colour of the first Order is the most vivid of any; and successively in the following Orders, in the second, third, &c. *it is less and less vivid.** 898

* 893

When a Plate of Air is enlighten'd with heterogeneous Rays, as that between the Glasses of the Telescopes, or any *Plate* like it of any other Substance, as in *Experiment* 1. and 2. several of the

the Rings seen in the last Experiment are confounded together, and that Colour is seen which is made of their Mixture; for *the same Thickness*
899 *of a Plate is often required for reflecting different Colours of various Orders*; so a Plate which reflects the Violet of the third Order, does also reflect the Red of the second Order, as may be deduc'd from the last Experiment, if you attentively consider it; therefore in the first and second Experiment, the third violet Ring is confounded with the outward Edge of the second red Ring, and Purple Colour is produc'd; yet all the Red of the second Order is not absorb'd, because the red Ring is wider than the violet one.

900 *The more the thickness of a Plate is increas'd, the more Colours it reflects, and different ones*, of different Orders; the violet Plate of the tenth Order falls in with the blue one of the ninth Order, and the yellow one of the eighth Order; and lastly, with the red one of the seventh Order; and the Colour of the Plate is made up of a Mixture of those Colours.

901 *If* in the first and second Experiments *a Spectator look obliquely upon the Plates*, such as that made of Air, and that which is made of Water, the Rings will be dilated as they are seen more obliquely; that is, in that Motion of the Eye *the Colour of the Plate* in a determinate Place *is chang'd*; yet the Dilatation is greater in the first Experiment; which proves, that *the Colour is more chan-*
902 *ged by the Obliquity of the Rays, if the Plane be encompass'd with a denser Medium, than if it be inclos'd by a rarer Medium.*

Plate XVIII. *Fig.* 7.] The Demonstration of which Proposition is easily deduc'd from the Laws of Refraction. Let L and *l* be thin Plates, the last encompass'd with a denser, and the first with a rarer Medium; let them both be of the same thickness;

thickneſs; if the Rays A B, *a b*, equally inclin'd to the Plates, fall upon them, there will be at L a Refraction towards the Perpendicular*; on the * 624
contrary, at *l* the Rays are refracted from the Perpendicular*; and tho' B D and *b d* are equal, * 625
b c is longer than B C; and therefore there is a greater Change in the Motion of the Light in the Plate *l* than in the Plate L. *The Denſity of the* 903
Plate L *being increas'd, the Medium with which it is encompaſs'd remaining the ſame, there will be a leſs* Difference between B C and B D, and therefore a leſs *Change of Colour*; and *if the refracting Power* 904
of the Plate be ſo *increas'd*, that the refracted Rays (whatever be the Obliquity of the incident ones) ſhall not ſenſibly differ, *there will be no ſenſible Difference in the Colour of the Plate, whatever Situation the Eye is plac'd in.*

Hence we may eaſily deduce, that *the Colour of* 905
ſome Plates will vary by changing the Poſition of the Eye, and that the Colour of others is permanent.

C H A P. XXIII.

Concerning the Colours of natural Bodies.

WHat relates to the Colours of all Sorts of Bodies, may be eaſily deduc'd from what has hitherto been explain'd.

We have ſhewn that the Rays of Light have Colours peculiar to themſelves, and unchangeable, ſo as not to be chang'd by Reflexion.* * 863

Therefore *the Rays reflected from Bodies, accord-* 906
ing as a greater or leſs Refrangibility is proper to the Colour of the Body itſelf, have a greater or leſs Refrangibility.

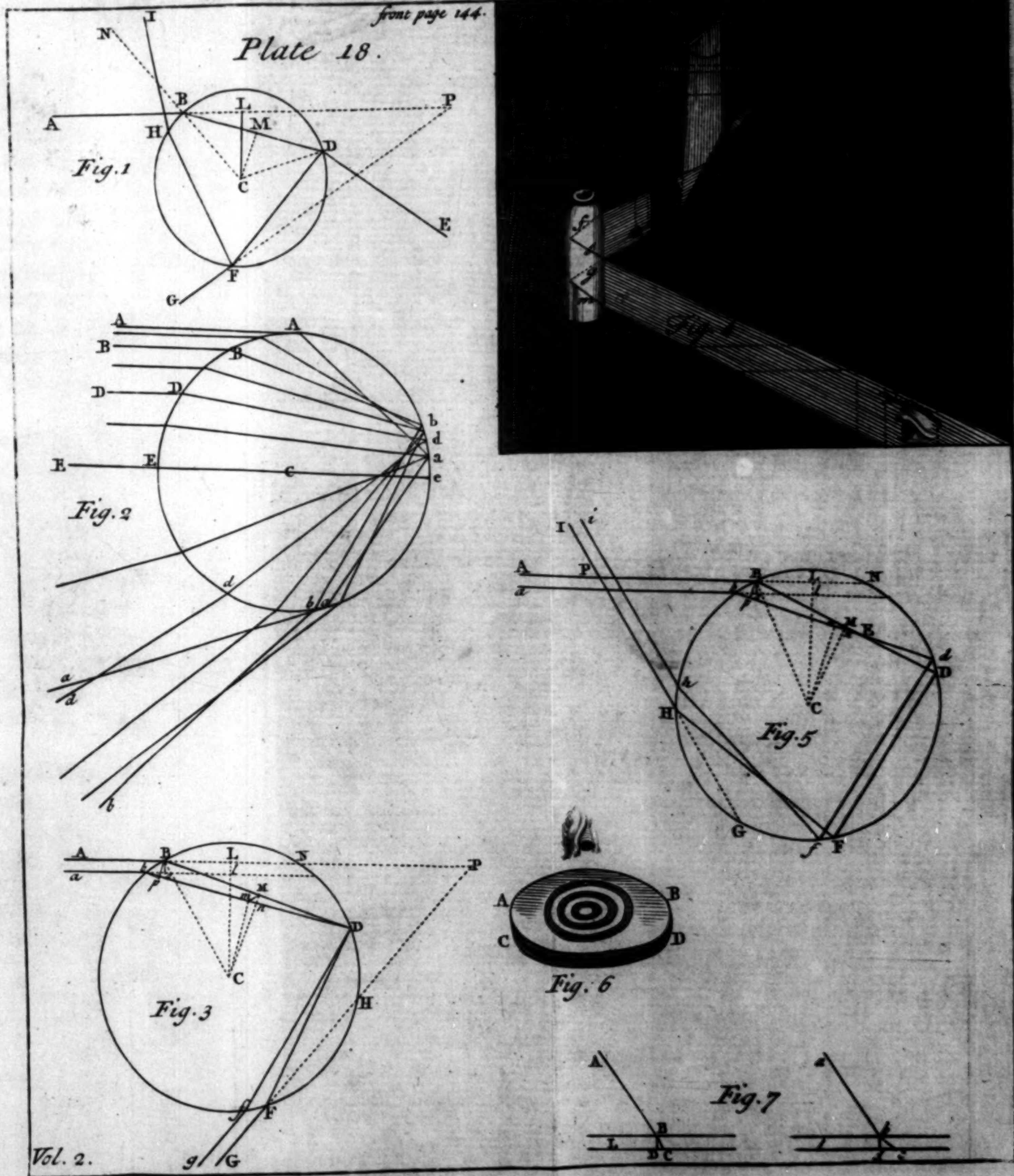
Experiment 1.] In the middle of a black Paper fix two ſquare Pieces of Ribbon, the one red, and the other violet, which muſt be join'd ſo as to touch one another at their Sides, in the ſame manner as the Red and Violet Colours in the third Experiment of *Chap.* 19. The black Paper muſt be ſo plac'd, that the Ribbons may be well enlighten'd by the Light that comes into the Room thro' the Window; if a Spectator looks at theſe Ribbons thro' a Priſm, as in the Experiment above-mention'd, the Colours will appear ſeparated, in the ſame manner as in that Experiment.

Experiment 2. *Plate* XIX. *Fig.* 2.] Place the two Ribbons mention'd in the former Experiment at R and V; let the laſt be violet, the firſt red; let them be enlighten'd by the Flame of a Candle; at ſix Feet diſtance place the convex Lens V (of which mention has been made in *Exper.* 6. *Cap.* 19.) at the diſtance of about ſix Feet, you will have the Repreſentation of the Ribbon R upon a white Paper at *r*; at a leſs diſtance you will have an exact Repreſentation of the other at *v*. You may determine when the Repreſentations are exact, by binding black Threads upon the Surface of the Ribbons; for theſe Threads appear diſtinctly where the Repreſentation is exact.

907 That *Bodies have various Colours, becauſe different Rays are reflected from Bodies differently colour'd*; and that *a Body appears of that Colour which ariſes from the Mixture of the reflected Rays*, may not only be deduc'd from the foregoing Experiments, but may be alſo demonſtrated directly by others.

Experi-

Plate 18.



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Experiment 3.] Take two Bodies of any Kind, the one red, the other blue, let them be enlighten'd ſucceſſively in a dark Place by the Colours of the colour'd Image, which is made by the Refraction of the Priſm, every one of the Colours will be reflected by both; but the red Rays are copiouſly reflected from the red Body, whilſt the blue Body reflects but few of them, which plainly appears by comparing both Bodies when they are enlighten'd by the red; the contrary may be obſerv'd in blue Colours, which are copiouſly reflected from the blue Body, whilſt only a few are reflected from the red one.

The Rays which are not reflected from a Body, penetrate into it, and there ſuffer innumerable Reflexions and Refractions, as we have explain'd between N° 842. and 843. till at length they unite themſelves to the Particles of the Body itſelf*; therefore *a Body grows hot ſo much the ſooner* * 546
as it reflects Light leſs copiouſly; for which reaſon 908
a white Body, which reflects almoſt all the Rays 909
with which it is enlighten'd*, *heats the ſloweſt*; * 870
whilſt a black Body, into which almoſt all the Rays penetrate, becauſe only few are reflected*, *acquires Heat ſooner than any other*. * 845

To determine that Conſtitution of the Surfaces of Bodies upon which their Colour depends, we muſt take notice of the ſmalleſt Particles of which theſe Surfaces are made up; theſe Particles are tranſparent*, and are ſeparated by a Medium of * 841
different Denſity from the Particles themſelves; * 843
they are alſo thin, otherwiſe the Surface would as it were be cover'd by a tranſparent Body*, and * 843
the Colour would depend upon the Particles under theſe; therefore in the Surface of every colour'd Body there are innumerable ſmall thin Plates; but by leſſening the Plate, keeping the

ſame thickneſs, its Properties, as to the Reflexion of Light, are not chang'd; for the leaſt Plate, in reſpect of the Rays of Light, is very large; wherefore what has been demonſtrated in the preceding Chapter, may be applied to theſe Plates in the Surfaces of Bodies; from whence we deduce the following Concluſions.

910 *The Colour of a Body depends upon the Thickneſs*
* 890 *and Denſity of the Parts of the Body, which are in*
911 *the Surface, between the Pores of the Body*.*
* 898, *The Colour is ſo much the more vivid and homoge-*
899,
900. *neous, as the Parts are thinner*.*

912 Cæteris paribus, *the aforeſaid Parts are of the*
* 896 *greateſt thickneſs when the Body is red, and of the*
861 *leaſt when violet*.*

913 *The Parts of Bodies are much denſer than the Me-*
* 902, *dium contained in their Interſtices*.*
903,
904. *This Denſity is leſs in* the Tails of Peacocks, and
914 in ſome Silks, and in general in all *Bodies whoſe*
* 901 *Colour varies according to the different Situation of*
903 *the Eye*.*

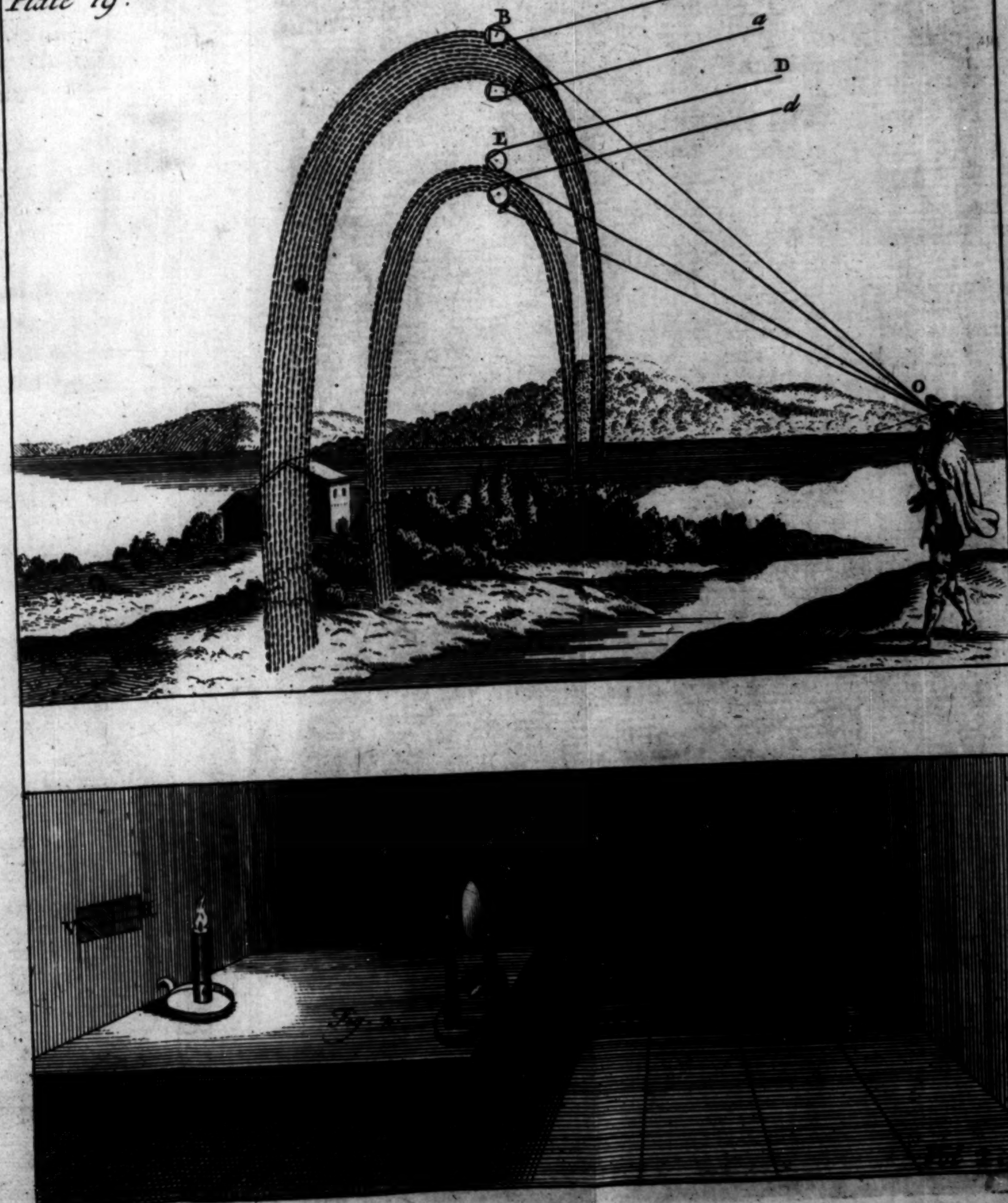
915 *The Colour of a Body is more obſcure and darker*
* 891 *when a denſer Medium enters its Pores**, for then the Parts, upon which its Colour depends, are ſurrounded by a denſer Medium than before.

We experience this in all Bodies which are thoroughly penetrated by Water and Oil; when the Bodies are dry they recover their former Colour, unleſs in ſome Caſes, in which ſome Parts are carried away by the Action of the Water or Oil, or when ſome Parts of the Water or Oil are ſo united with the Parts of the Body, as to change the Thickneſs of the Plates.

From ſuch a Cauſe are deduc'd the Changes in the Colours of ſome Liquors, by their being mix'd
916 with others; *often the ſaline Particles ſwimming in one Liquid, unite themſelves to the ſaline Particles ſwimming in another; or the united Particles are ſe-*

parated

Plate 19. *front page 146*



parated by the Actions of others that are superadded; *on all which Accounts* the thickneſs of the Particles *is chang'd*, and together with it *the Colour of the Liquids* *. * 888

917 *Sometimes the Colour of a Liquid is different, when ſeen by reflected Rays, from what it is when ſeen by tranſmitted ones*; we have ſhewn before whence this ariſes *. * 887

Experiment 4.] An Infuſion of *Lignum Nephriticum*, that is not too much tinged, appears blue by reflected Rays; but yellow if the Phial which contains the Infuſion be plac'd between the Light and the Eye.

Experiment 5.] If you pour Spirit of Vinegar into the Infuſion of *Lignum Nephriticum*, it will appear yellow in any Poſition whatever.

In this Caſe the thickneſs of the Particles is chang'd, and the Rays that were tranſmitted thro' every one of them, are now intercepted; but tho' the Liquor is plac'd between the Eye and the Light, it is ſeen by reflected Rays; for we may eaſily conceive that ſuch Rays come to the Eye by the various Reflexions which the Light undergoes in the Liquid; but this Colour only is ſenſible, becauſe the Rays cannot penetrate directly thro' the Liquid.

918 From this we may deduce the reaſon why *a colour'd Liquid in a Glaſs, of the Figure of an inverted Cone, if it be placed between the Eye and the Light, appears of a different Colour in different Parts of the Veſſel*; in the lower Part all the Rays which are tranſmitted thro' the Particles are not intercepted, then they are more and more intercepted, according as there is a greater Quantity of the Liquid between the Eye and the Light, till at length they come to be all intercepted, and

only those Rays which are reflected by the Particles penetrate the Liquid; in which Case the Colour coincides with the Colour of the Liquid seen by the reflected Rays.

919 *Clouds* often *appear very beautifully coloured*; they consist of aqueous Particles, between which Air is interspersed; therefore *according to the va-*
920 *rious thickness of those aqueous Particles*, the Cloud
* 888 will be of a different Colour *.

The End of the Third Book.

Mathematical Elements OF *Natural Philosophy*, Confirm'd by EXPERIMENTS.

BOOK IV.

Part I. *Of the System of the World.*

CHAP. I.

A general Idea of the Planetary System.

* HE who attentively considers that * 15
Space can be terminated by no Bounds, will scarce be able to deny, that the Supreme Almighty Intelligence has every where manifested the same Wisdom which he has shewn to the Inhabitants of the Earth in a small Compass. What I here call a small Compass, im-

menſly exceeds our Comprehenſion; yet it is but ſmall, compared with infinite Space.

921 *Our Earth, with ſixteen other Bodies* (for we have no Knowledge of any more) *moves in a determinate Space*; neither do theſe Bodies recede from, or come nearer to one another, beyond their ſet Bounds; and their Motions are perform'd according to unchangeable Laws.

Definition I.

922 *This Collection of ſeventeen Bodies is called the* Planetary Syſtem.

The whole Art of *Aſtronomy* is almoſt employed concerning theſe alone, and theſe will be chiefly my Subject in this Work; the other Bodies that conſtitute the Univerſe are too far diſtant from us for their Motions (if they are mov'd) to fall under our Obſervations; of theſe only the lucid Bodies can be perceiv'd by us, and of thoſe only the more remarkable ones, and which are leſs diſtant from us than the reſt; even moſt of ſuch as are ſeen by the Teleſcope are inviſible to the naked Eye.

Definition II.

923 All theſe Bodies are called *fixed Stars*.

They are called fixed, becauſe, as far as can be perceiv'd, they keep the ſame Poſition with reſpect to one another; we muſt take notice of ſomething peculiar concerning theſe hereafter.

924 But as to the Planetary Syſtem, *in this* we have ſaid *there are* ſeventeen *Bodies, which are all ſpherical*; *one only ſhines by its own Light, the reſt are opake, and are viſible only by the Light which they borrow from that.*

925 *The Sun is that lucid Body, and far the greateſt of all in the Planetary Syſtem; it is quieſcent in the middle*

dle of it, at least is agitated by a very small Motion.

DEFINITION III.

The other Sixteen are called *Planets*.

These are divided into two Classes; six are called the primary Planets; *ten are called the* secondary Planets. When we speak of the Planets without any distinction, we always understand the primary ones. 926

The primary Planets move round the Sun, and are carried at different Distances from it, in Curves that return into themselves. 927

A secondary Planet revolves round a primary one, and accompanies it in its Motion round the Sun. 928

The Planets in their Motions describe elliptic Lines, not much different from Circles; *and* all *those* Lines *are fixed*; at least there is but a small Change to be observed in a long Time in their Situation. 929

Plate XXIV. *Fig.* 3.] An elliptic Line is formed, if a Thread, whose Extremities are fix'd in the two Points F and *f*, is mov'd, remaining stretched; as is to be seen in this Figure, in which the Thread is represented at F *d f*, F E *f*, F B *f*; the Points F, *f*, are called the Foci; the Line A *a*, which passes thro' them, and is terminated on each side by the Circumference of the Ellipse, is called the *greater Axis*, and it is the greatest Line that can be drawn in the Ellipsis; the middle Point C of the Axis is the Center of the Ellipse; and the *lesser Axis* D *d* falls perpendicularly thro' this Point upon the *greater Axis*. 930

The Orbits of all the primary Planets are in such a Position, that one of their Foci falls in with the Center of the Sun; let the Ellipse A D *a d* represent the Orbit of a Planet, F will be the Center of the Sun. 931

DEFINITION IV.

932 *The Distance between the Center of the Sun and the Center of the Orbit is called* the Eccentricity of the Planet; as F C.

933 *In every Revolution the Planet approaches once to the Sun, and once recedes from it*; and at its greatest distance is at *a*, the Extremity of the greater Axis of the Orbit; and at its least distance in the opposite Extremity A.

DEFINITION V.

934 *That distance of the Planet from the Sun is called the* mean distance, *which is equally different from the greatest and the least*; at this distance the Planet is in the Extremities D, *d*, of the smaller Axis.

DEFINITION VI.

935 *The Point of the Orbit, in which the Planet is at its greatest distance from the Sun, is called the* Aphelium; as *a*.

DEFINITION VII.

936 *The Point of the Orbit, in which the Planet is at its least distance from the Sun, is called the* Perihelium,

DEFINITION VIII.

937 These Points are commonly called the *Auges*, or *Apsides*.

DEFINITION IX.

938 *The Line which joins the Apsides*, that is, the greater Axis of the Orbit, *is called* the Line of the Apsides.

939 *Every Orbit is in a Plane which passes thro' the Center of the Sun.*

DEFI-

DEFINITION X.

The Plane of the Orbit of the Earth is called the Plane of the Ecliptic. 940

This Plane is to be continu'd every way; and *Astronomers* consider the Position of the Planes of the other Orbits with respect to this.

DEFINITION XI.

The Points in which the other Orbits cut the Plane of the Ecliptic, are called the Nodes. 941

DEFINITION XII.

The Line which joins the Nodes of any Orbit, that is, the common Section of the Plane of the Orbit with the Plane of the Ecliptic, *is called* the Line of Nodes. 942

A Planet is not carried with an equal Celerity in 943
all the Points of its Orbit; the less it is distant from 944
the Sun, the swifter is its Motion; and the Times in which the several Arcs of its Orbit are run thro', are to one another as the Area's formed by Lines drawn from the Planet to the Center of the Sun; the Arcs A B and *a* E are run thro' in Times, which are to one another as the Area's of the mix'd Triangles A F B, *a* F E.

All the Planets are carried the same way, and their Motion in their Orbits is contrary to that Motion which we observe daily in all the celestial Bodies, by which in one Day they seem to be carried round the Earth; of which hereafter. 945

DEFINITION XIII.

A Motion, such as is that of the Planets in their Orbits, is said to be in consequentia, *and direct.* 946

DEFI-

Definition XIV.

947 *The contrary Motion is called a Motion* in antecedentia; *and ſometimes* retrograde.

948 *The more diſtant the Planets are from the Sun, the ſlower they move in their Orbits*; ſo that the periodical Times of the moſt diſtant ones are greater, both becauſe they have a greater Orbit to run thro', and a ſlower Motion.

Definition XV.

949 *The Line which paſſes thro' the Center of the Planet, and about which it moves, is called* the Axis of the Planet.

950 *The Planets*, at leaſt moſt of them, *and the Sun itſelf, move round their Axis*; there are two, of which, in this reſpect, Aſtronomers have been able to make no Obſervations, but which in all Probability have this Motion.

951 *This Motion* agrees or conſpires with the Motions of the Planets in their Orbits; that is, it is *in conſequentia.*

952 *The Axes* themſelves *are mov'd by a parallel Motion*, ſo that all the Points of the Axis of a Planet deſcribe equal and ſimilar Lines.

Definition XVI.

953 *The Extremities of the Axis are called* the Poles of the Planet.

954 *Plate* XX. *Fig.* 1.] Aſtronomers compare together accurately enough the Diſtances of the Planets from the Sun, to give us an Idea of the whole Syſtem. The Dimenſions of the Orbits are repreſented in this Scheme, in which the Points N N ſhew the Nodes of each Orbit.

955 Nevertheleſs *we cannot compare the Dimenſions of this Syſtem with any that we know upon the Surface of the Earth*; for no Aſtronomers will aſſert, that

that the Observations made concerning such a Comparison are free from Error.

But that the several Parts of the System may 956
be compared together, we suppose the mean Distance of the Earth from the Sun divided into 1000 equal Parts, which we make use of in measuring the other Distances.

The Sun ☉, as was said before, is agitated by 957
a small Motion in the middle of the System; it moves round its Axis in the Space of 25 Days; and its Axis is inclin'd to the Plane of the Ecliptic, making an Angle of 87 Deg. 30 Min.

Mercury ☿ is the least distant from the Sun of 958
any of the Planets; its mean Distance from the Sun is 387, its Eccentricity 80; the Inclination of its Orbit, that is, the Angle form'd by the Plane of its Orbit with the Plane of the Ecliptic, is 6 Degr. 52 Min. it performs its Revolution round the Sun in 87 Days, 23 Hours.

The next is *Venus* ♀, whose Distance from the 959
Sun is 723, its Eccentricity 5, the Inclination of its Orbit 3 Deg. 23 Min. It performs its periodical Motion in 224 Days, 17 Hours; and its Motion round its Axis is perform'd in 23 Hours.

The third Planet in order from the Sun is our 960
Earth ⊕; its mean Distance from the Sun is 1000, its Eccentricity 169; it is moved in the Plane of the Ecliptic; its periodical Time is 365 Days, 5 Hours, 51 Min. and the Motion about its Axis is perform'd in 23 Hours, 56 Min. 4 Sec. Its Axis makes an Angle with the Plane of the Ecliptic of 66 Deg. 31 Min.

The mean Distance of *Mars* ♂ from the Sun 961
is 1524, its Eccentricity 141, the Inclination of its Orbit 1 Deg. 52 Min. its periodical Time 686 Days, 23 Hours; its Revolution about its Axis is perform'd in 24 Hours, 40 Min.

Jupiter

962 *Jupiter* ♃, the biggeſt of all the Planets, is diſtant from the Sun, at a mean diſtance, 5201; its Eccentricity 250; the Inclination of its Orbit 1 Deg. 20 Min. the periodical Time 4332 Days, 12 Hours; and its Revolution about its Axis in 9 Hours and 56 Min.

963 The mean Diſtance of *Saturn* ♄, the moſt diſtant Planet from the Sun, is 9538; its Eccentricity 547; the Inclination of its Orbit 2 Deg. 30 Min. the periodical Time 10759 Days, 7 Hours; it is encompaſs'd with a Ring, which does not touch the Planet, but never leaves it; this Ring is not viſible without a Teleſcope.

The mean Diſtance being given, if you add the Eccentricity, you will have the greateſt Diſtance; but if you ſubtract the Eccentricity from the mean diſtance, you will have the leaſt di-
* 836 ſtance.*

964 The three Planets, *Mars*, *Jupiter*, and *Saturn*, which are more diſtant from the Sun than the Earth, are call'd the *ſuperior Planets*; *Venus* and *Mercury* are call'd the *inferior ones*.

965 *Of the primary Planets, three are accompanied by ſecondary ones.*

Five Planets call'd Satellites, move about *Saturn*; four about *Jupiter*; one about the Earth (*viz.*) the Moon.

The ſecondary Planets, except the Moon, are not viſible to the naked Eye.

966 *The Satellites, by Lines drawn to the Center of the primary Planets, deſcribe Area's about them proportional to the Times*; as has been ſaid of the primary Planets with reſpect to the Center of the
* 944 Sun.*

967 *The Moon moves about the Earth in an Ellipſe,*
968 *one of whoſe Foci is in the Center of the Earth*, from
969 which the mean diſtance of the Moon is 60 Semidiameters of the Earth and a half; *its Eccentricity*

is

is liable to change; the mean one is of 3 Semidiameters and a Third; the Plane *of its Orbit* forms an Angle with the Plane of the Ecliptic of five Degrees; *but this Inclination is not constant, or* 970
always the same. In the Motion of the Moon round the Earth, neither the Line of the Nodes, nor the Line of the Apsides, is carried in a parallel Motion, but the *Line of the Nodes* Westward, or in *antecedentia*; *the Lines of the Apsides* Eastward, or in *consequentia*; the first performs it Revolution in about 9 Years, the second in 19; the periodical Time of the Moon's Motion about the Earth is 27 Days and about 7 Hours; and it is turn'd about its own Axis exactly in the same Time.

Plate XX. *Fig.* 2.] The first, or inmost of the 971
Satellites of *Jupiter*, is distant from *Jupiter*'s Center $2\frac{5}{6}$ Diameters of *Jupiter*; it is mov'd round *Jupiter* in one Day, 18 Hours, 28 Min.

The Distance of the second is 4 and an half Diameters of *Jupiter*; its periodical Time is 13 Hours, 18 Min.

The Distance of the third is $7\frac{1}{7}$ Diameters; its periodical Time 7 Days, 4 Hours.

The fourth is distant $12\frac{2}{3}$ Diameters; it performs its Motion in 16 Days, 18 Hours, 5 Min.

Plate XX. *Fig.* 3.] The first, or inmost Satel- 972
lite of *Saturn*, is distant from *Saturn*'s Center $\frac{19}{48}$ of a Diameter of the Ring; its periodical Time is 1 Day, 21 Hours, 18 Min.

The Distance of the second is $1\frac{1}{4}$ Diameter of the Ring; its periodical Time is two Days, 17 Hours, 41 Min.

The Distance of the third is $1\frac{3}{4}$ Diameter of the Ring, its periodical Motion is 4 Days, 13 Hours, 47 Min.

The

The Diſtance of the fourth is 4 Diameters of the Ring, its periodical Time 15 Days, 22 Hours, 41 Min.

The diſtance of the fifth is 12 Diameters of the Ring; its periodical Time is 79 Days, 7 Hours, 53 Min.

973 Concerning the Motion of theſe, as alſo of the Satellites of *Jupiter* about their Axes, we can hitherto determine nothing certain from aſtronomical Obſervations.

If we take notice of the Diſtances and periodical Times of the Planets, we ſhall find that the following Rule holds good in our Syſtem; wherever ſeveral Bodies are moved round the ſame Point, that is, *about the* Sun, Saturn, *and*
974 Jupiter *(viz.) the Squares of the periodical Times are to one another as the Cubes of the mean Diſtances from the Center.*

975 *Plate* XX. *Fig.* 4.] To give a Notion of the Dimenſions of the Bodies themſelves in our Syſtem, we have contriv'd the fourth Figure, in which all the primary Planets and *Saturn*'s Ring are deſcrib'd according to their Dimenſions; the Sun, whoſe Magnitude exceeds all the reſt, is repreſented by the greateſt Circle *(Fig.* 1.) that is, the Circle which terminates the Figure.

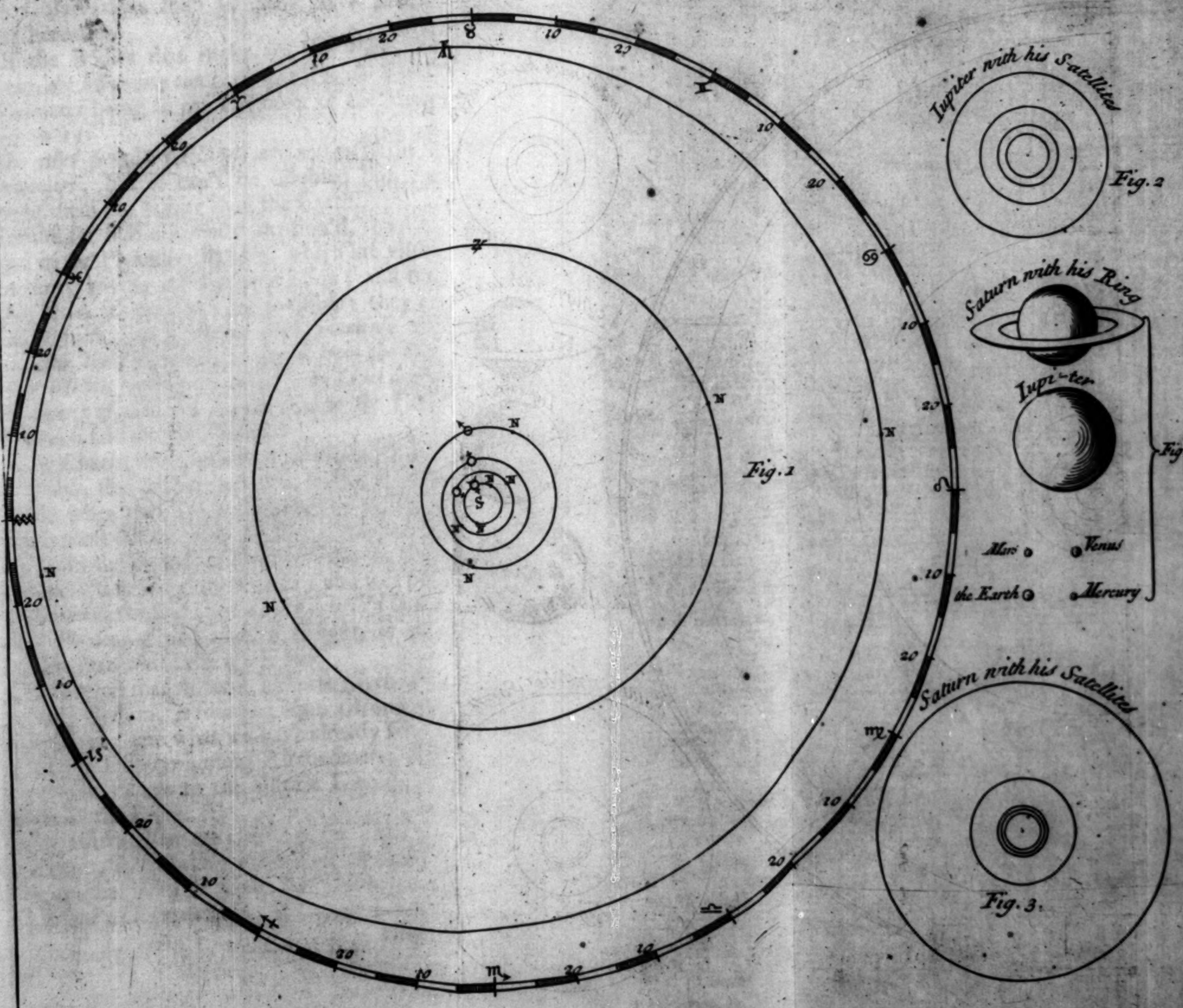
These Dimenſions repreſent the Proportions of the Bodies one to another exactly enough, if you except the Earth, which, for the Reaſon already
* 955 mention'd *, cannot be ſo compar'd with the other Bodies, as to leave no room to doubt what Proportion it bears to them.

976 Yet *the Earth's Diameter may be meaſur'd,* and contains 3.400669 Perches, each of which is equal to 12 *Rhynland* Feet; but altho' the Diameters of the other Planets may be compar'd together, and with the Sun's Diameter, yet it can't be determin'd how many Feet they contain, till

after

front page 158

Plate 20



after Obſervations ſhall be made at a proper Time hereafter.

Of the Bodies that make up the Planetary Syſtem, *the Moon only can be compar'd to the Earth*, its Diameter being to the Diameter of the Moon as 40 to 11. 977

The other ſecondary Planets are not meaſur'd by Aſtronomers, but it can't be doubted but that ſome of them are bigger than the Earth. 978

Beſides the Bodies already mention'd, there are others in the Planetary Syſtem, which are viſible for a time, as they come near the Sun; and then recede from it, and become inviſible; they are called *Comets*; they *appear moſt commonly with Tails, and the Tail is always turn'd from the Sun; in their Motion they deſcribe Area's, by Lines drawn to the Center of the Sun, proportional to the Times*, as has been ſaid of the Planets.* 979 980

* 944 966

As to Comets, it is probable that they move in elliptic Orbits, that are very eccentric, ſo that they are inviſible when they are in that Part of the Orbit which is moſt diſtant from the Sun; which is deduc'd from the Periods of ſome of them that have been obſerv'd to be pretty regular; and it is plain from Obſervations, that *ſome have deſcrib'd in their Motion Portions of very eccentric Eclipſes, in one of whoſe Foci was the Center of the Sun.* 981 982

The Notion that we have hitherto given of the Planetary Syſtem, is founded upon aſtronomical Obſervations; and what we have already ſaid admits of no Diſpute among Aſtronomers, if we except what relates to the elliptic Line and the Motion of the Earth.

Some affirm, that the Orbits of the Planets are not elliptic, but that in their Motion they deſcribe another Oval. *Kepler* has deduc'd from *Tycho Brahe*'s Obſervations, that theſe Lines are elliptic;

elliptic; and we shall shew in the following Part that no other Curves can be describ'd by the Planets.

Those that say the Earth is at rest, have no astronomical or physical Argument for a Foundation of their Opinion; that is, don't reason from *Phænomena*; neglecting the Simplicity of the System, and the Analogy of the Motions, they assert, that their Opinion is not contrary to Observations; in which they err, as we shall shew in the following Part.

CHAP. II.

Concerning the apparent Motion.

WHoever, after having read the former Chapter, looks upon the Heavens, will scarcely believe that he beholds the System which is explain'd there; and a more exact Consideration of the heavenly Motions will increase his
983 Doubt: no wonder, *since we can observe very little in the Heavens but false Appearances.*

The common Observer of the Heavens is a Spectator, who thinking himself to be at rest, is carried about by various Motions, and beholds Bodies, concerning whose Distance and Magnitude he makes false Judgments. The true System of the World was unknown for many Ages, even to the most exact Observers of the Heavens.

But

But we must explain how all things which are observ'd in the heavenly Bodies have Place in the System that has been explain'd, in respect of a Spectator upon the Earth; that is, we shall deduce the Appearances from the true Motions; which cannot be done, unless we first lay down some general things concerning the apparent Motion in general. 984

It is certain that we have no Art by which we can discover the true Motion, only the relative Motion can be perceiv'd by the Senses; and it is that only concerning which we treated in the former Chapter. Who can reasonably affirm or deny, that all the Bodies which are known to us, are not carried in a common Motion thro' the immense Spaces?

The relative Motion is to be distinguish'd from the apparent one; for the apparent Motion is the Change which appears to be in the Situation of the Bodies, and depends upon the Change of the Picture in the bottom of the Eye; for Objects have the same apparent Relation to one another as their Representations have in the Eye, for they are seen as they are painted in the Eye*; and the Change in that Picture, from the Motion of the Bodies, most commonly differs from the Change of the Relation between the Bodies themselves; as follows from the Formation of that Picture. 985 * 716

The Heavens are nothing but an immense Space, which cannot be seen, and would appear black*, if innumerable Rays of Light, flowing from the heavenly Bodies, did not continually penetrate our Atmosphere; most of them come to us from the Bodies in right Lines, yet a great many suffer various Reflexions in the Atmosphere, and enlighten the whole Atmosphere; which is the reason that in the Day Bodies are enlighten'd even 986 * 845

without the Reflexion of the Clouds, to which the Rays of the Sun cannot come directly.

These Rays are heterogeneous and white, for there are Bodies enlighten'd by these Rays which appear white; and these Bodies seen thro' Prisms, at the Extremities, are ting'd with Colours, which
* 874 does not happen in an homogeneous Colour*; also a Circle of white Paper, of half an Inch diameter, being put upon black Cloth, if it is enlighten'd by these Rays, it will appear oblong
* 861 thro' the Prism*; and the same Colours which are observ'd in the Rays of the Sun, are seen here in the same manner; all which things would not happen, if the Air, as many think, was a blue Liquid, that is, thro' which only the Sun's blue Rays, at least mostly such, pass.

987 *When we look at the black Sky, the white Rays* before mention'd *enter our Eyes, whence the blue Colour of the Sky arises*; because we are accustom'd to see a Colour where there is a colour'd Object, we also refer the Colour of the Heavens to an Object; but since this is seen equally towards all
988 Parts, *we conceive a concave spherical Surface, in whose Center we are placed; we imagine this Surface to be opake, and therefore distant from us beyond all visible Bodies.*

When a Body is between a Plane and the Eye, of whose distance we cannot judge, the Body appears to us to be applied to the Plane, whatsoever the distance is between that and the Plane; for there is no reason why the Parts of the Plane, which are painted at the Sides of the Image of the Body in the Eye, should not appear at the same distance with the Body.

989 Thence also *all the celestial Bodies* (of which the least distant from us (*viz.*) the Moon) is yet so remov'd, that we can give no Judgment of its
* 732 distance*, *are referr'd to that imaginary Sphere*

above-mention'd, and they all appear equally distant, and seem to move in the Surface of a concave Sphere; so the Moon appears to be among the fixed Stars, altho' its distance bears scarcely any sensible Proportion to the distance of *Saturn*; and the distance even of *Saturn* itself is nothing, compar'd with the immense distance of the fixed Stars; it is no wonder therefore that the common People know nothing of the Magnitude of the celestial Bodies and the Immensity of the Heavens.

We see from what has been said, how the Motion of any Body being given, and the Motion of the Earth being known, the apparent Motion may be determin'd.

We have said that a Sphere is imagin'd beyond the fixed Stars, in whose Center is the Spectator*. * 988
The Orbit of the Earth is so small in respect of the Diameter of this Sphere, that the Center of the Sphere is not sensibly chang'd by the Alteration of the Place of the Spectator, whilst he is carried along with the Earth; wherefore *in all* 990
the Points of the Earth's Surface, and at any Time, the Inhabitants of the Earth imagine the same Sphere, to which they refer the heavenly Bodies, and which hereafter we shall call *the Sphere of the fixed Stars*.

These things being laid down, *if we conceive a* 991
Line to be drawn thro' the Earth and a Body, which being continu'd beyond the Body, cuts the aforesaid Sphere, we have a Point, to which the above-mention'd Body is referr'd, *and which is the apparent Place of that Body*.

Whilst the Body, or the Earth, or both are
mov'd, this Line is mov'd also, and *the apparent* 992
Motion is the Line, which is describ'd amongst the fixed Stars by the Extremity of the Line above mention'd, *which goes thro' the Earth and the Body, whose apparent Motion is observ'd*.

993 Therefore *the same Appearances will follow from the Earth's being mov'd out of its Place, as if the Body had been mov'd; and the same also may be deduc'd from the Motion of both.*

994 But *if the Body and the Earth be so mov'd, that the Line which passes thro' these Bodies be carried in a parallel Motion, the Body will seem to be at rest among the fixed Stars*; because in this Case the Space gone thro' by the End of the Line among the fixed Stars, cannot exceed the Space gone thro' by the Earth; but the Line that is equal to the whole Space which the Earth can go thro' at so great a distance as the fixed Stars, is not sensible to us.

995 *From the Motion of the Earth round its Axis* there is also *produc'd an apparent Motion*, which will be easily deduc'd in its proper Place from the Foundation laid down in this Chapter.

That the apparent Motion differs from the relative, and is varied by the Motion of the Spectator, is what Sailors every Day observe.

CHAP. III.

Of the Phænomena or Appearances of the Sun from the Motion of the Earth in its Orbit.

Plate XXI. Fig. 1.] LET the Sun be at S, and the Earth in its Orbit at T, and let *r s* be the Sphere of the fixed Stars; the apparent
* 991 Place of the Sun will be at *s* *. *When the Earth is*
996 *carried in its Orbit from* T *to t, the Sun seems to move in* consequentia, and to run thro' the Arc
* 992 *s r* *, which measures the Angle *r S s* equal to the Angle T S *t*; so that the Celerity of the apparent Motion of the Sun depends upon the Celerity of the angular Motion of the Earth, with respect

 to

to the Center of the Sun; which Motion increases upon a double Account; on account of the distance from the Sun being lessen'd, and the Celerity of the Earth being increas'd; both which Causes always concur; * *wherefore the Inequality of the apparent Motion of the Sun is sensible. In a whole Revolution of the Earth, the Sun also seems to run thro' a whole Circle.* * 944 997 998

DEFINITION I.

This apparent Way of the Sun is called the Ecliptic Line; it is the Section of the Sphere of the fixed Stars with the Plane of the Ecliptic, suppossed to be continu'd to this Sphere. 999

This Way is divided into 12 equal Parts, each of which contains 30 Degrees; these Parts are called the Signs, and are distinguish'd by these Names: *Aries* ♈, *Taurus* ♉, *Gemini* ♊, *Cancer* ♋, *Leo* ♌, *Virgo* ♍, *Libra*, ♎, *Scorpius* ♏, *Sagittarius* ♐, *Capricorn* ♑, *Aquarius* ♒, *Pisces* ♓. Whence these Parts have their Names, we shall explain when we treat of the fixed Stars.

The Sun is longer a going thro' the six first Signs than the six last, and the difference is nine Days. 1000

Altho' a Circle has neither Beginning nor End, yet when several Points must be determin'd in it, some Point must be taken as *the Beginning*; this, *in the Ecliptic Line, is the first Point of* Aries; we shall shew how it may be determin'd hereafter; it is not fixed to one Place among the fixed Stars; therefore *the Orbits of the Planets*, which alter so little, that they may be look'd upon as unchangeable, * *don't preserve the same Situation, in respect of this Point.* 1001 1002 * 929

Definition II.

1003 *The Distance of the Sun from the first Point of* Aries, *measured in* consequentia, *is called* the Sun's Longitude.

1004 *The Longitudes of the other heavenly Bodies are measured after the same manner in the Ecliptic; they*
1005 *are referr'd to this Line, by conceiving a great Circle to pass thro' the Body, and cut the Ecliptic perpendicularly*; for the Point in which the Ecliptic is cut by this Circle, determines the Longitude of the Body.

Definition III.

1006 *The Distance of a heavenly Body from the Ecliptic is called* its Latitude; it is measur'd by an Arc of a great Circle perpendicular to the Ecliptic, intercepted between the Body and the Ecliptic.

Definition IV.

1007 *If we imagine a Line to go thro' the Center of the Sphere of the fixed Stars, and perpendicular to the Ecliptic, the Points in which this cuts the above-mentioned Sphere, are called* the Poles of the Ecliptic.

Definition V.

1008 *The* Zodiac *is a Zone which is imagin'd in the Heavens, which the Ecliptic Line cuts into two equal Parts, and which, on either side, is terminated by a Circle parallel to the Ecliptic Line, and eight Degrees distant from it.* On account of the small Inclinations of the Orbits of the Planets, and the Moon to the Plane of the Ecliptic, no Bodies of the
1009 Planetary System appear without the *Zodiac*.

Defi-

Definition VI.

Those of them that have the same Longitude are 1010
said to be in Conjunction.

Definition VII.

Those whose Longitudes differ 180 *Degrees, are* 1011
said to be in Opposition.

CHAP. IV.

Of the Phænomena of the inferior Planets, arising from the Earth's and their own Motions in their Orbits.

Plate XXI. *Fig.* 2.] LET S be the Sun, A V B *v* the Orbit of an inferior Planet; let T be the Earth in its Orbit, and *a* v *b* Part of the Sphere of the fixed Stars; the apparent Place of the Sun is v*. * 991

If from the Earth there be drawn to the Orbit of the Planet the Tangents T A *a*, T B *b*, it is evident that the Planet, in its apparent Motion, is never remov'd farther from the Sun than the Distance v *a*, v *b*; and that the Planet accompanies it in its apparent Motion round the Earth.

Definition I.

The apparent Distance of the Planet from the Sun 1012
is called its Elongation; v *a* or v *b* is *the greatest*
Elongation; this varies upon two Accounts (*viz.*) 1013
because the Earth and the Planet revolve in elliptic Lines*. * 929

The Planet performs its Motion sooner than 1014
the Earth, * therefore *in its Motion* it *passes between* * 948
the Earth and the Sun, and then moves beyond the

Sun, in respect of the Earth; so that it is in Conjunction with the Sun in two Manners, but *never in Opposition.*

That we may have an Idea of the apparent Motion of the Planet, we must conceive the Lines T B *b*, T S v, T A *a*, to move along with the Earth, so that the Points A, V, B, and *v*, whilst the Earth performs its Revolution, may run thro' the Orbit of the Planet; but the Planet, which moves swifter, passes successively through these Points over and over.

1015 *When* it is carried in its Orbit from V to D, it seems to move among the fixed Stars from v to *d*; in this Case *the apparent Motion is in* antece-
1016 dentia, and *the Planet is retrograde*; in D it is said to be *stationary*, because *it appears for some Time in the same Place among the fixed Stars*; this obtains when the Orbit of the Planet, in the Place in which the Planet is, is so inclin'd to the Orbit of the Earth, in the Place in which the Earth is, that if the Line *t d* be drawn parallel to the Line T D, and at a small distance from it D *d* be to T *t* as the Celerity of the Planet in its Orbit to the Celerity of the Earth; these Lines are run
* 53 thro' in the same Time; * and the Line which is drawn thro' the Earth and the Planet is carried in a parallel Motion; for which Reason the ap-
* 992 parent Place of the Planet is not chang'd*.

Between *d* and B the Orbit of the Planet is more inclin'd to the Orbit of the Earth, wherefore the Extremity of the Line passing thro' the Earth and the Planet (altho' the Planet moves
1017 swifter than the Earth) is carried *in consequentia*, *towards which* Part also *the apparent Motion of the*
* 992 *Planet is directed**; yet since the apparent Motion of the Sun exceeds the apparent Motion of the Planet, the Elongation is increas'd, which becomes greatest when the Planet is at B. Whilst the

the Planet goes thro' the Arc B *v*, its apparent Motion is alſo *in conſequentia*, and exceeds the apparent Motion of the Sun, to which it is coming, and then goes beyond it, receding from it till it comes to A. Between A and E the Motion *in conſequentia* is continu'd; but the Sun, whoſe apparent Motion in this Caſe is ſwifter, as has been explain'd concerning the Arc *d* B, comes towards the Planet, and the Elongation is dimi-
niſh'd. At E, in the ſame manner as at D, *the* 1018
Planet is ſtationary; between E and V it is again retrograde.

The Orbit of the Planet is inclin'd to the Plane
of *the* Ecliptic, * therefore it *does not ſeem to move* * 958
in the Ecliptic Line, but ſometimes leſs, ſometimes 959
more diſtant from it, and *appears to be carried in an irregular Curve, which ſometimes cuts the Ecliptic.*

Plate XXI. *Fig.* 3.] Let N V N be the Orbit of the Planet, whoſe Nodes are N N; let S be the Sun; T *t* the Orbit of the Earth in the Plane of the Ecliptic; the Earth T; the Planet V. If V A be imagin'd to paſs thro' the Planet, and to be perpendicular to the Plane of the Ecliptic, the Angle V T A, or rather the Arc which
meaſures it, is the Latitude of the Planet;* this *1006
is called *the geocentric Latitude*, to diſtinguiſh it from the Latitude of the Planet ſeen from the Sun, which is called *the heliocentric Latitude*, and is in that Caſe the Angle V S A. Here we ſpeak of the *geocentric Latitude*, becauſe we examine the Phænomena as they appear from the Earth.

When a Planet appears in the Node, it appears in 1019
the Ecliptic Line; and the Curve, which is deſcribed by the Planet, by its apparent Motion in the
Zodiac, cuts the Ecliptic Line; *as the Planet re-* 1120
cedes from the Node, its Latitude is increaſed, which is alſo different, according to the Situation of the Earth;

Earth; so the Planet remaining at V, the Latitude is greater if the Earth be at T, than if it was at *t*. Now, if the Earth remaining in its Place, we imagine the Planet to be carried from V to *v*, the Angle *v* T B will be less than the Angle V T A upon a double Account, from the Planet coming nearer the Node, and the Spectator being mov'd farther off.

Now if we consider that both the Earth and the Planet are continually mov'd, we shall easily conceive that the Latitude is chang'd every Moment from each Cause, which sometimes act contrariwise, and sometimes conspire in increasing and diminishing the Latitude; whence it necessarily follows, that the apparent Motion is perform'd in an irregular Curve, which, as was said before, cuts the Ecliptic as often as the Planet passes the Node, that is, twice in each of its Revolutions; this Curve also does not recede from the Ecliptic, on either side, beyond certain Limits in the Zodiac.

We discover also some remarkable Phænomena of the inferior Planets by means of the Telescope, which are owing to their Opacity.

Plate XXI. *Fig*. 4.] Let S be the Sun, T the Earth, A, B, C, v, D, E, F, V, an inferior Planet, *ex gr. Venus* in its Orbit; this Planet shines with Light borrow'd from the Sun, and that Hemisphere only which is turn'd to the Sun is enlighten'd, the other Hemisphere is invisible; therefore that Part only of the enlighten'd Hemisphere which is turn'd to the Earth can be seen from it; in V the Planet cannot be seen; in v it would appear round, if the Sun's Rays did not hinder it from being seen.

1021 Going from v *the Planet continually decreases*; at D it has the Figure *d*; at *e* and *f* it is drawn as it appears at E and F, and continues to decrease

crease *till it vanishes at* V, *and then again increases successively, changing its Figure* till the whole enlighten'd Hemisphere be turned towards the Earth.

When the Node is at V, or near it, *the Planet appears in the very Disk of the Sun,* and as it were applied to *it,* and *is observ'd as a black Spot which moves on the Sun's Surface*; in this Case, properly speaking, we don't see the Planet, but we perceive where it intercepts the Sun's Rays. 1022

The less distant the Planet is from the Earth, the greater it appears *, and the more lucid; but as it comes nearer the Earth, the lucid Part that is visible is less; so that on one account the Light increases, and on another it is diminish'd; *and there is a Distance at which the reflected Light is greatest.* 1023 * 733

CHAP. V.

Concerning the Phænomena of the superior Planets, arising from their Motions and the Motion of the Earth in their respective Orbits.

THE apparent Motions of the superior Planets do in many things agree with what has been explain'd in respect of the inferior Planets, and in many things disagree; *they do not always accompany the Sun, but are often observed in Opposition*; but in their Opposition (as has been said of the inferior Planets) *they do not always seem to be carried in* consequentia, *but often appear stationary, and often retrograde.* 1024 1025

Plate

1026 *Plate* XXII. *Fig.* 1.] Let M be *a superior Planet*, for Example, *Mars* in its Orbit, A T H B the Orbit of the Earth; the periodical Time of the Earth is shorter than the periodical Time of
* 948 *Mars**, therefore the Earth in its Motion goes between it and the Sun; in which Case the Planet *appears* at F, among the fixed Stars, *opposite to the Sun*; thro' M draw the Lines B M, A M, that touch the Earth's Orbit, which being continu'd go to G and D in the Sphere of the fixed Stars; let us imagine that whilst the Planet is carried about in its Orbit those Lines are also moved, so that the Points A and B, in which the Lines that go thro' the Planet touch the Orbit of the Earth, perform a Revolution in the periodical Time of the Planet; now since the Earth revolves faster, it passes thro' the Points A and B in its Motion; in this Motion the apparent Place of the Planet seen from the Earth, is not remov'd from the Place of the Planet seen from the Sun beyond F D and F G. Let T be such a Point in the Orbit of the Earth, that the Line *t m* being drawn, may be parallel to T M; let T *t* be to M *m* as the Celerity of the Earth to the Celerity of the Planet, in which Case these small Lines
* 53 are gone thro' in the same Time; * in the mean
* 994 time the Planet seems to be at rest, * and is said to be stationary; in the same manner it is stationary when the Earth is at H. In the Motion of the Earth between T and H, the Planet appears to move in *antecedentia* from E thro' F, and is said to be retrograde; whilst the Earth goes thro' the rest of its Orbit the Planet is direct.

1027 The Phænomena which relate to the Latitude, are like those which have been explain'd in re-
* 1008 spect to the inferior Planets*.

1028 *Jupiter* and *Saturn* encompass the Orbit of the Earth at a great distance, wherefore almost their whole

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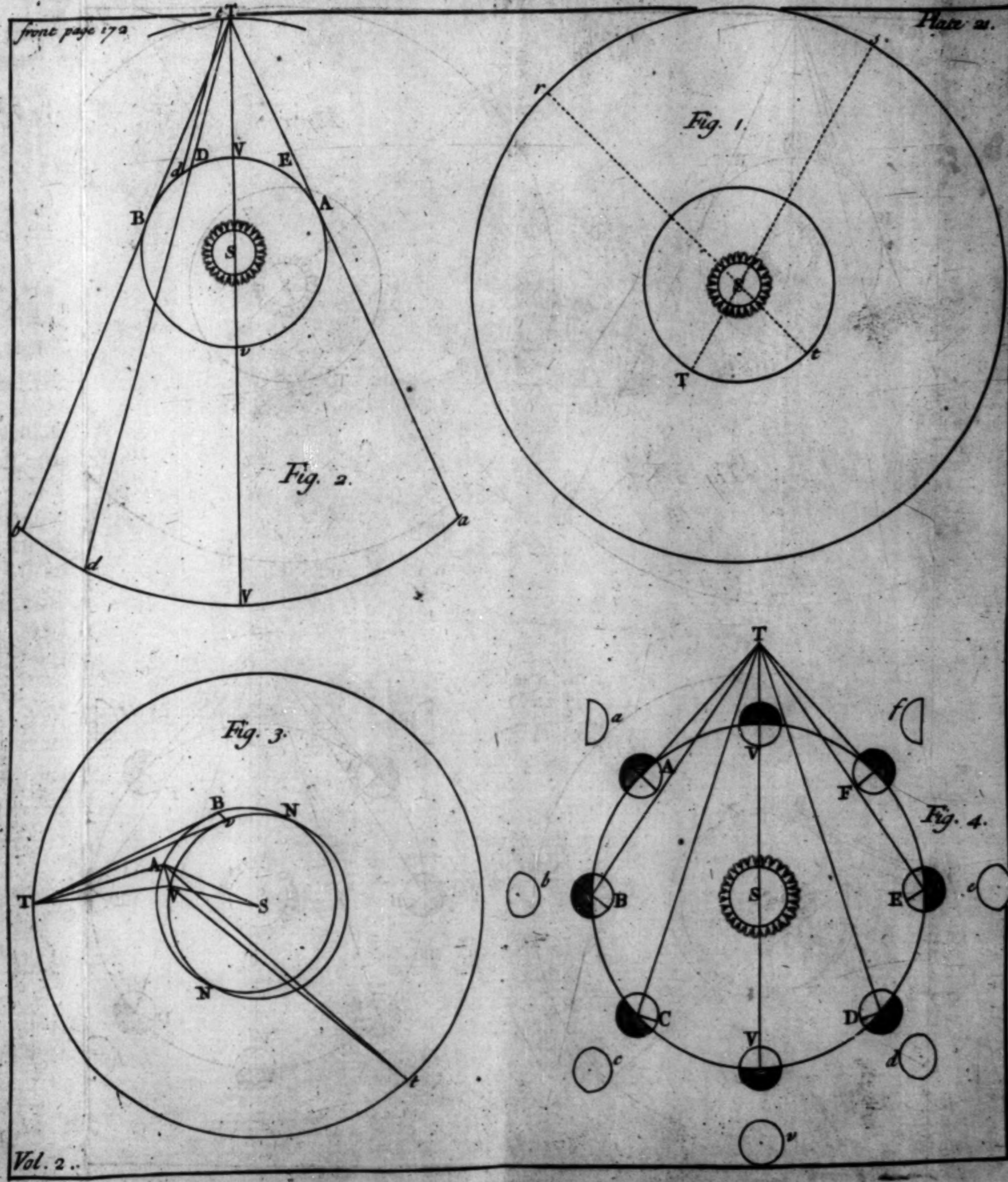
Plate 21.



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whole Hemispheres, which are enlighten'd by the Sun, are visible from the Earth, and therefore these Planets *always appear round.*

Because *Mars* is less distant, it *appears a little gibbous between the Conjunction and Opposition with the Sun.* 1029

CHAP. VI.

Concerning the Phænomena of the Satellites, from their Motion in their Orbits; where we shall speak of the Eclipses of the Sun and Moon.

THE *Satellites of* Jupiter *and* Saturn *do always accompany their Primaries in their Motion, and never appear to recede from them beyond certain Limits on either side,* which may be easily determin'd from their Distances from their Primaries, *and they are alternately carried* in *antecedentia* and in *consequentia*; sometimes all of them are on the same side of the primary Planet, and sometimes the primary is observ'd to be between them; 1030
they are all *always in the same right Line, or very little distant from it*; all which things may be deduc'd from this, that the Motion about the primary Planets is perform'd in Planets that make small Angles with one another, and with the Plane of the Ecliptic. 1031

All *the Satellites of* Saturn *or* Jupiter are not always visible at the same time, *sometimes* they *are hid by their Primary, and often immers'd in its Shadow.* 1032

DEFINITION I.

Plate XXII. *Fig.* 2.] Such an Immersion in the Shadow is call'd an *Eclipse of the Satellite.* 1033

Let

Let S be the Sun, T *t* the Orbit of the Earth; I *Jupiter*, M *m* the Orbit of a Secondary of *Jupiter*; whilst the Secondary moves from M to *m* it undergoes an Eclipse, and not being enlighten'd by the Sun, becomes invisible; if the Earth be at T, the Emersion into the Shadow is easily obser-ved; on the contrary, the Emersion is more sensible if the Earth be placed at *t*.

1034 Among the Bodies that accompany *Saturn* we
* 963 have said that there is *a Ring*, * concerning which it is to be observ'd, *that an Observer upon the Earth never sees it wider than it is represented in the 4th Fig. of Plate* XX. *and that sometimes it is invisible*; namely, when the Plane of the Ring being continu'd goes thro' the Earth, for the thickness of the Ring is not sensible; the Ring is also invisible when its Plane continu'd passes between the Earth and the Sun, for then the enlighten'd Surface of the Ring is turn'd from the Earth; in each Case *Saturn* appears round; yet in the last Case, by reason of the Rays that are intercepted by the Ring, there appears a black Belt upon the Surface of the Planet, like that which is occasion'd by the Shadow of the Ring.

The Phænomena of the Earth's Satellite, namely, of the Moon, are very remarkable in respect to us, and therefore particularly to be explain'd.

1035 It is very often in Conjunction with the Sun; and as often in Opposition to it, but not at every Revolution of the Moon in its Orbit; for whilst the Moon, after one entire Revolution of 27 Days and 7 Hours, returns again to the Place among
1036 the fixed Stars, in which it was in Conjunction
* 960 with the Sun, the Sun is gone from that Place,
996 and is about 27 Deg. distant from it; * therefore
998 *the neighbouring Conjunctions are* 29 *Days and a half distant from one another*.

DEFI-

DEFINITION II.

The lunar periodical Month *is the Time of one Revolution of the Moon in its Orbit.* 1037

DEFINITION III.

The Moon's ſynodical Month, or a Lunation, *is the Time that the Moon ſpends between the two next Conjunctions with the Sun.* 1038

The Moon is inviſible in its Conjunction with the Sun, becauſe the enlighten'd Hemiſphere is turn'd from the Earth. Let T (*Plate* XXII. *Fig.* 3.) be the Earth, N the Moon between the Sun and the Earth, the enlighten'd Hemiſphere will be *m l i*, which cannot be ſeen from the Earth. 1039

Whilſt the Moon is carried in its Orbit *from the Conjunction to the Oppoſition*, the enlighten'd Part, which is directed towards the Sun, *does continually become more and more viſible to the Inhabitants of the Earth*; and in the Points A B C the Moon does ſucceſſively acquire the Figures *a b c*. 1040

At P, *in its Oppoſition with the Sun*, *it appears round*; *then going thro'* D E F *it decreaſes*, as it is repreſented at *d e f*. 1041

DEFINITION IV.

The Conjunction of the Moon with the Sun is called the New-Moon. 1042

After the Conjunction, the Moon is as it were renew'd.

DEFINITION V.

The Oppoſition of the Moon with the Sun is called the Full-Moon, *becauſe the whole Moon appears enlighten'd.* 1043

DEFI-

Definition VI.

1044 *The Conjunction and Opposition of a Satellite with the Sun, are called by the common Name* Syzygies.

1045 At A and F the dark Part of the Moon is a little enlighten'd by the Rays that are reflected from the Earth, and therefore it is seen by a Spectator to whom the Sun is not visible; that is, in the first Case, after the setting of the Sun; and in the second, before its Rise.

Definition VII.

1046 *When the Light of the Sun is intercepted by the Moon, so that, in respect of any Observer upon the Earth, the Sun is partly or wholly cover'd, the Sun is said to undergo an* Eclipse.

Properly speaking this is an Eclipse of the Earth, on whose Surface the Shadow or *Penumbra* of the Moon falls.

Definition VIII.

1047 An Eclipse of the Moon *is the Obscuration of the Moon by the Shadow of the Earth.*

1048 *The Eclipse of the Sun is never observ'd, except at the time of the New-Moon.*

1049 *The Moon is never eclips'd but at the time of the Full-Moon.*

1050 Yet the Luminaries are not eclips'd at every one of the *Syzygies*, because the Moon does not
* 969 move in the Plane of the Ecliptic, * in which the Sun and Earth always are; wherefore, upon account of the Moon's Latitude, its Shadow at the New-Moon often does not touch the Earth; and itself at the Full-Moon passes beside the Shadow of the Earth.

1051 But *when the Moon* has no Latitude, or but very little; that is, when it *is in the Node, or near it, at its* Syzygies, *an Eclipse is observed*; in that

Case the Moon appears to be in the Ecliptic, or very near it; and this it is that has given the Name to that Line.

Plate XXIII. *Fig.* 1.] That what relates to the Eclipse of the Moon may appear the more plainly, let O O be the Way of the Moon, R R the Plane of the Ecliptic, the Center of the Earth's Shadow is always in it; * N is the Node of the Moon's Orbit. * 904 939

If the Center of the Earth's Shadow be at A, the Moon that goes by at F will not be darken'd.

If the Moon be less distant from the Node at the Full-moon, as at G, the Shadow of the Earth is at B, and *the Moon is darken'd in part; this is called a partial Eclipse.* 1052

If, supposing the Shadow at D, the Moon be full, *the Moon* will *be wholly darken'd* at I; it runs into the Shadow at L, and goes out of it at H; and *the Eclipse is said to be total.* 1053

The Eclipse is said to be central when the Center of the Moon goes thro' the Center of the Shadow, which only happens in the very Node N. 1054

We have hitherto spoken of the Shadow of the Earth, because when we mention the Earth we understand its Atmosphere, which is join'd to it, of which we have spoken elsewhere; * *the Shadow of the Atmosphere is* properly *consider'd in lunar Eclipses,* for the Shadow of the Earth itself does not reach the Moon. * 418 1055

Plate XXIV. *Fig.* 1.] Let T be the Earth, the Atmosphere about it F D G G D F; the Sun's Rays B D, B D, touching the Atmosphere; these go strait on, and terminate the Shadow of the Atmosphere, out of which if the Moon be, it is immediately enlighten'd by the Sun's Rays; but it is not enlighten'd in the same manner all the while it is between B D and B D.

1056 *The Rays which enter the Atmosphere obliquely* are
* 617 refracted, * and as they come towards the Earth, they continually penetrate into a Medium, which
* 424 is denser and denser, * and therefore are every
429 Moment inflected, and *move into Curves*; so the
* 617 Rays E F E F penetrate the Atmosphere in the Curves F G F G that touch the Earth; all the Light between E F E F is intercepted by the Earth, and the Rays G A G A terminate the Earth's Shadow.

The Light between E F and B D being refracted by the Atmosphere, is scatter'd between G A and B D continu'd; and beyond A, the Point of the Earth's Shadow, the Lights that
1057 come from all Parts are confounded, but are continually weaker and weaker the farther from the Earth; so that *the Shadow of the Atmosphere is* not a perfect Shadow, but *a weak Light*, whereby the Moon is visible in an Eclipse.

1058 *The Shadow of the Atmosphere* is conical, because the Sun's Diameter is greater than the Diameter of the Atmosphere, which is scarce bigger than that of the Earth; and this Cone *does not reach quite to Mars*, as appears from immediate Observations; but the Shadow of the Diameter, in the Place where it is cut by the Moon's Orbit, is scarce one Fourth less than the Diameter of the Earth.

With the same Reasoning that we have prov'd that the Moon comes into the Shadow of the Atmosphere, when the Moon in its full is in the Node, or near it, it is also prov'd that the Moon's Shadow falls upon the Earth *at the New-Moon, when the Moon is in the Node, or near the Node*;
1059 therefore in that Case *the Sun undergoes an Eclipse*, concerning which several things are to be observed.

Plate

Plate XXII. *Fig.* 4.] Let S be the Sun, T the Moon, let the Shadow of it fall upon any Plane G H; this Shadow is encompaſs'd with a *Penumbra*, for beyond L and E that Plane is enlighten'd by one entire Hemiſphere of the Sun; as you go from L to H, and from E to G, the Light is continually diminiſh'd; and near G and H the Rays come to the Plane only from a ſmall Part of the Sun's Surface.

Definition IX.

This diminiſh'd Light, which encompaſſes the Shadow G H *every way, is called the* Penumbra. 1060

In the Eclipſe of the Moon the Shadow of the Earth is encompaſs'd with *the like Penumbra*, but this is only ſenſible near the Shadow, and therefore *has but a ſmall Breadth*; *but* if *an Obſerver* be plac'd upon a Plane upon which the Shadow falls, he *may obſerve the whole Penumbra*; as is the Caſe *in the Eclipſe of the Sun*. An Obſerver I or F can only ſee the Semidiameter of the Sun, the reſt of the Diameter is hid by the Moon; and going from L towards H, the Sun is continually more and more hid by the Moon, till it becomes wholly inviſible in the Shadow itſelf. 1061 1062

Hence it follows, that *there is a ſolar Eclipſe, tho' the Shadow of the Moon does not touch the Earth, provided the Penumbra comes to its Surface*; and alſo, *that the Eclipſe is not obſerv'd in all the Places in which the Sun is viſible*; *and that it is different*, according as the Shadow or a different Part of the Penumbra goes thro' the Place, *in the Places in which it is obſerv'd.* 1063 1064 1065

But the Eclipſe of the Moon is every where the ſame, where the Moon is viſible, during the Eclipſe. 1066

But when the Shadow itſelf of the Moon falls upon the Earth, the Sun's Eclipſe is ſaid to be total; *if only the Penumbra reaches the Earth, it is ſaid to be* 1067

partial; and this is what happens when we consider an Eclipse in general.

1068 But as to particular Places, *it is said to be total in those Places where the Shadow passes*; *central in those* where the Center of the Shadow passes; that is, *where the Center of the Moon covers the Sun's Center*; and lastly, *partial*, *where the Penumbra only goes by*; and this is drawn in *Fig.* 6.

1069 *Plate* XXII. *Fig.* 4.] *The wider the Shadow* GH *is*, *the more Places is the Eclipse of the Sun total in*, *and the longer is the Sun wholly obscur'd*; but the Breadth of the Shadow is different, according to the different Distances of the Moon from the Earth, and of the Earth from the Sun.

1070 *If there be an Eclipse of the Moon*, *supposing the Earth in the Perihelion*, and *the Moon in the Apogæum*, that is, at the greatest Distance from the Earth, the Shadow of the Moon does not reach the Earth, and *the Moon does not cover the whole Sun*; *such an one is* call'd *an annular Eclipse*, and is represented in *Fig.* 5.

CHAP. VII.

Of the Phænomena arising from the Motion of the Sun, the Planets, and the Moon, about their Axes.

1071 THE *Sun's Motion about its Axis is sensible*, *by observing the Spots*, which are observ'd very often upon the Sun's Surface; these Spots seem to change their Figure and Situation every Day, and sometimes to move swifter, sometimes slower; all which things may be easily deduc'd from the Motion of a spherical Surface; and the Sun, which, if it was not moved by such a Motion, would only once in a Year successively turn its whole

whole Surface to the Earth, now shews it to the Inhabitants of the Earth in less than the Space of one Month.

Such like Phænomena arise from *the Rotation of Jupiter, Mars, and Venus, about their Axis*, which Motions *become sensible, by observing the Spots in the Surface of the Planets.* 1072

Whilst the Earth is mov'd round its Axis, the Observer, who is carried round, imagines himself to be at rest, and all the heavenly Bodies to be in motion.

DEFINITION I.

The Points in which the Axis of the Earth, being continued both ways, touches the Sphere of the fixed Stars, are called the Poles of the World. 1073

DEFINITION II.

The apparent Motion arising from the Motion of the Earth about its Axis, is called the diurnal Motion. 1074

DEFINITION III.

A Plane is conceiv'd to pass thro' the Center of the Earth, perpendicular to its Axis, and continu'd every way; and the Circle, in which it cuts the Sphere of the fixed Stars, is called the celestial Æquator. 1075

In the Motion of the Earth round the Sun the Æquator is moved; but since the Plane of this Circle is carried by a parallel Motion, *the celestial Æquator is not moved**. 1076

* 994

DEFINITION IV.

Circles, whose Planes go through the Axis of the Earth, are called Meridians. 1077

They all pass thro' the Poles of the World, and are perpendicular to the Æquator. 1078

Definition V.

1079 *The Arc of any Meridian, which is intercepted between the Æquator aud a Star, is called* the Declination of that Star.

Plate XXIII. *Fig.* 2.] Let an Observer be upon the Earth T, who directs his Sight along TA; after a little Time, when the Line T A shall be carried by the Motion of the Earth to T *a*, if the Spectator directs his Sight thro' the same Line, the Body A will appear to have been carried thro' the Arc *a* A; but when the Line has return'd to its former Situation T A, the Body will seem to have perform'd one whole Revolution; but if he directs his Sight along the Axis of the Earth produc'd, because that is at rest, the Body which is seen in the Axis will appear not to

1080 have moved, therefore *in the Poles of the World the*

*1073 *diurnal Motion is not observ'd** ; but that Bodies which are near the Poles are moved round them, is plain, and that the Body by its diurnal Motion describes so much a greater Circle round the immoveable Pole as it is farther distant from it;

1081 therefore *the whole Sphere of the fixed Stars seems to revolve about the Axis of the Earth continu'd*, in antecedentia, *in that Time in which the Earth really turns about its Axis*; therefore the diurnal Motion is common to all the celestial Bodies, except so far as it is disturb'd by the Motions above-mentioned.

The Æquator is equally distant from both Poles, and divides the Heavens into two Hemispheres, whose middle Points are the Poles, which therefore are equally distant from the several

1082 Points of the Æquator; therefore *the heavenly Bodies which are in the Æquator, by their diurnal Motion seem to describe the Æquator itself*, the greatest Circle of all that can be describ'd by the diurnal

urnal Motion; *the other Bodies describe Circles pa-* 1083
rallel to the Æquator.

The Axis of the Earth is inclin'd to the Plane of the Ecliptic in an Angle of 66 Deg. 31 Min.* * 960
the Poles of the World therefore *are distant from the* 1084
Poles of the Ecliptic 23 Deg. 29 Min. *and the Plane of the Æquator makes an Angle with the Plane of the Ecliptic of* 23 Deg. 29 Min. Both Planes pass thro' the Center of the Earth; but since this may be look'd upon as the Center of the fixed Stars,
* it follows, that *the Æquator and the Ecliptic Line* 1085
are great Circles, which are inclin'd to each other, * 988
and *cut one another in two opposite Points, in the be-* 990
ginning of Aries, *and the beginning of* Libra; which Points, in the Way of the Sun, are determined
by these Intersections.* *1001

When the Sun is in those Points, it seems to describe 1086
the Æquator by its diurnal Motion; * *when it is car-* 1087
ried about *in the Ecliptic* by its apparent Motion, *1082
it continually recedes more and more from the Æquator, and its Declination is increased, *and it*
describes less Circles every Day; * *till it comes to its* *1083
greatest distance from the Equator, which is 23 Deg. 1088
29 Min. * *then it comes back to the Equator again,* *1084
and goes beyond it also 23 Deg. 29 Min. *advancing towards the opposite Pole.*

DEFINITION VI.

Those Circles, describ'd by the Sun in its diurnal 1089
Motion, which are most distant from the Equator, that is, 23 Deg. 19 Min. *are called* the Tropics.

One touches the Ecliptic Line in the first Degree of *Cancer*, and is call'd the Tropic of *Cancer*; the other is call'd the Tropic of *Capricorn*, and passes thro' the first Point of the Sign *Capricorn*, and there touches the Ecliptic Line.

DEFINITION VII.

1090 *The Pole of the World, which is next to the Tropic of* Cancer, *is called the* Arctic Pole, *and also the* North Pole; *the opposite is called the* Antarctic, *and also the* South Pole.

DEFINITION VIII.

1091 *The Circles* that are describ'd in the diurnal Motion by the Poles of the Ecliptic, that is, by the Points *which are distant from the Poles of the World* 23 Deg. 29 Min. *are called the* Polar Circles.

The Arctic Polar Circle is that which surrounds the Arctic Pole, the other opposite one borrows its Name from the Antarctic Pole.

1092 There remains to be explain'd *the Moon's Motion about its Axis, whose Effect is, that the same Face of the Moon is always turn'd towards the Earth.*

Plate XXII. *Fig.* 3.] Let the Moon be at N, the Face which is turn'd to the Earth is *m n i*; if the Moon did not turn about its Axis, and all its Points were carried thro' parallel Lines, the Line *m i* would coincide with the Line *l n* in the Situation of the Moon at B, and the aforesaid Hemisphere *m n i* would be at *l m n*; but because whilst the Moon describes a fourth Part of its Orbit, it performs likewise a Fourth of its Revolution round its Axis, the Face, which would be at *l m n*, is now at *m n i*, that is, again turn'd to the Earth. After the same manner it is prov'd, that this same Face *m n i*, when the Moon is at P, is seen by an Observer on the Earth, and that it is turn'd towards the Earth at E; as also in all other Points of the Moon's Orbit.

1093 *The Axis of the Moon* is not perpendicular *to the Plane of its Orbit*, but *a little inclin'd* to it; the Axis keeps its Parallelism in its Motion round the Earth, as has been said of the primary Planets; * therefore

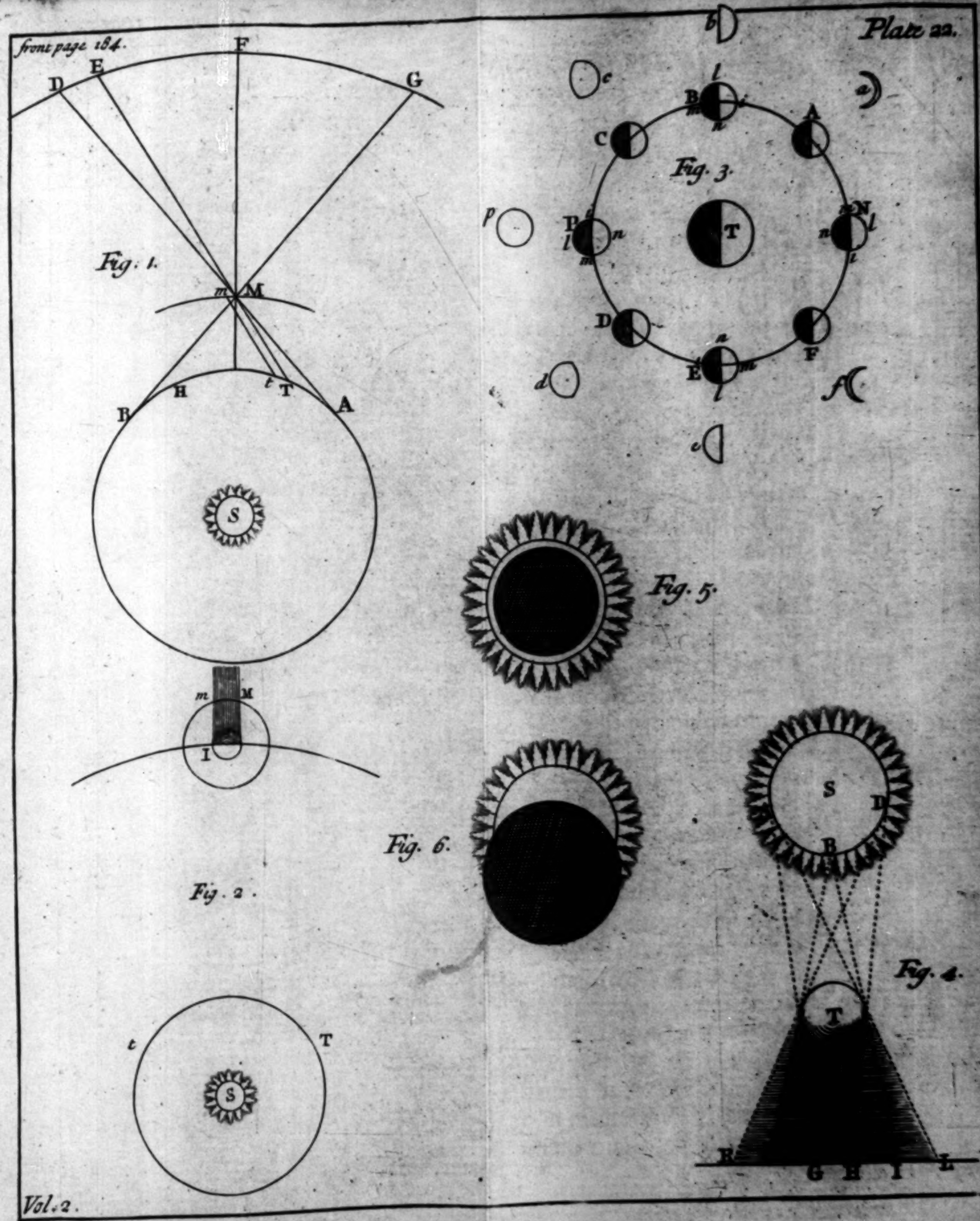
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Plate 22.
Fig. 1.
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Fig. 2.
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Fig. 3.
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Fig. 4.
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Fig. 5.
Fig. 6.
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* therefore it changes its Situation, in respect of an Observer upon the Earth, to whom sometimes one, sometimes the other Pole of the Moon is visible; whence *it seems to be agitated by a* sort *of libratory Motion.* There is another libratory Motion observ'd in the Moon; the Motion about the Axis is equable, and it is carried in its Orbit with an unequal Celerity; * therefore when the Moon is at its *Perigæum*, that is, at its least distance from the Earth, where it is moved the swiftest in its Orbit *, that Part of its Surface, which, on account of its Motion in the Orbit, would be turn'd towards the Earth, is not wholly turn'd from it on account of its Motion round its Axis; therefore some of that Part of the Surface of the Moon, which before was not visible, is seen at the side; which, when the Moon is at its *Apogæum*, is again visible.

* 953 · 1094 · * 966 · * 966

CHAP. V.

Of the Phænomena which relate to the Surface of the Earth, and its particular Parts.

WE have explain'd the celestial Phænomena hitherto examin'd, by considering the Spectator as carried about by those Motions wherewith the Earth is really moved; now we shall consider him as plac'd upon the Surface of the Earth, and carried from one Place to another upon it.

The first Phænomena to be here observed is, 1095
that, *by reason of the Interposition of the Earth, one Half of the Heavens is invisible to the Observer, who is plac'd upon the Surface of the Earth.*

DEFINITION I.

That Circle in the Heavens which separates the vi- 1096
sible from the invisible Part, when the Rays are not inter-

intercepted by the Inequalities of the Earth's Surface, *is called the* Horizon.

When the Height, to which the Spectator can be raiſed above the Surface of the Earth, is very ſmall, compared with the Semidiameter of the Earth, the Eye of the Spectator may be look'd upon as placed in the Surface itſelf.

Plate XXIII. *Fig.* 4.] Let the Earth be at T, and the Obſerver at S, and P E *p e* the Sphere of the fixed Stars; if you conceive a Plane at H H to touch the Earth and go thro' S, it will be the Plane of the Horizon, whoſe Section with the Sphere of the fixed Stars is the Horizon. A Plane, as *h h*, is conceiv'd to go thro' the Center of the Earth, parallel to H H; the diſtance *h* H is inſenſible, by reaſon of the immenſe diſtance of the fixed Stars; therefore the Section of that Plane, with the Sphere above-mention'd, may be taken
* 994 for the Horizon.*

DEFINITION II.

1097 *The Aſcent of the* Stars *above the Horizon is called their* Riſe.

DEFINITION III.

1098 *The Deſcent below the Horizon is called the* ſetting *of the Stars.*

DEFINITION IV.

1099 *If we conceive a Line drawn thro' the Obſerver and the Center of the Earth,* which muſt neceſſarily be perpendicular to the Horizon, *it will reach the Point* Z *among the fixed Stars, which is called the* Zenith.

DEFINITION V.

1100 *The Point* N, *oppoſite to it, is called the* Nadir.

DEFINITION VI.

1101 *The Section which a Plane of the Meridian, that goes thro' the Obſerver, makes with the Horizon, is called the* Meridian Line, and is directed from North to South.

DEFI-

Definition VII.

The Eastern Part of the Heavens *is that, from which we see the Bodies rise above the Horizon*; *and the* East Point *is that, in which a Line directed Eastwards, perpendicular to the Meridian Line, and going thro' the Observer, cuts the Sphere of the fixed Stars.* 1102

Definition VIII.

The Point opposite to this is called the West Point, *and the* Western Point of the Heavens *is opposite to the Eastern Part.* 1103

Definition IX.

The Amplitude *is an Arc of the Horizon, which is contain'd between the East or West Point, and the Point in which the Star rises or sets*; the first is called the rising, and the other the setting Amplitude; and each is either Northern or Southern Amplitude. 1104

Definition X.

The Height or Altitude of a Star above the Horizon, *is the Arc of a Circle perpendicular to the Horizon, in whose Center the Spectator is, terminated by the Horizon and the Star.* 1105

Definition XI.

The difference of the height of a Star, according to the different Position of the Observer, as he is supposed in the Center, or on the Surface of the Earth, is called the Parallax of the Star. 1106

There is only the Parallax of the Moon which can be determin'd by Observations; the distance of the rest of the Bodies in the planetary System is too great to be compared with the Semidiameter of the Earth; and the Parallax depends upon the Ratio which the Semidiameter of the Earth has to the distance of a Planet; therefore even *the Parallax* 1107

1108 *rallax of* Mars, *in Opposition with the Sun, is too small for the nicest Observations.*

1109 Where there is a *Parallax,* it *diminishes as a Body ascends above the Horizon, and vanishes in the Zenith.*

The apparent height of the Stars is alſo chang'd upon another Account, which equally affects all
1110 the heavenly Bodies; the Rays are inflected *by the*
1111 *Refraction of the Atmosphere**, and *the Stars appear*
*1956 *higher than they are**; *yet the higher they are the less*
* 624 *is that Inflexion**, becauſe the Rays fall leſs ob-
* 639 liquely on the Surface of the Atmoſphere; *in the*
1112 Zenith *there is no Refraction**, *even at the distance*
* 629 *of* 20 *or* 30 *Degrees from the* Zenith *it is not sensible.*

1113 Since *the Stars* are raiſed *by this Refraction,* they *are visible before they come to the Horizon.*

Plate XXIV. *Fig.* 2.] All theſe things relate to the Surface of the Earth in general; now we muſt examine the ſeveral Parts of it, theſe are determin'd by referring to the Earth the ſeveral Circles
1114 which we have before conſider'd in the Heavens; ſo *on the Earth we consider the Æquator, the Meridians, the Tropics, and polar Circles*; and theſe Circles divide the Surface of the Earth in the ſame manner as the Sphere of the fixed Stars is divided by the Circles in the Heavens; and therefore the Circles in the Heavens, and thoſe upon the Earth, do ſo mutually correſpond with each other, that a Line being drawn from the Center of the Earth to a Circle in the Heavens, it will go thro' the ſame Circle in the Earth. If the Poles are P *p*, the Æquator will be E *e*, the Tropics T T, *t t*, and the polar Circles A A, *a a*.

Definition XII.

1115 *The Meridian, which goes thro' a Place, is called* the Meridian of the Place.

The

The Plane of it is perpendicular to the Horizon, because it goes thro' the Center of the Earth and the Observer. 1116

*A Meridian Line drawn in any Place, is part of the Meridian of the Place**. 1117

*1101

Definition XIII.

The Latitude of a Place *is its distance from the Æquator*, that is, the Arc intercepted between that Place and the Æquator. 1118

Definition XIV.

Circles parallel to the Æquator are called Circles of Latitude. 1119

By determining the Latitude of the Place, we determine the Circle of Latitude, which goes thro' the Place; now to determine the Situation of several Places in respect of each other, we must determine Places upon the several Circles; which is done, by supposing a Meridian to pass thro' any remarkable Place, which by its Section determines a Point upon each Circle of Latitude, from which the Distances of Places are measur'd.

Definition XV.

The Meridian above-mention'd, taken at pleasure, is called the first Meridian. 1120

Definition XVI.

The Distance of a Place from the first Meridian, measur'd on a Circle of Latitude that goes thro' a Place, is called the Longitude of the Place. 1121

Astronomers refer every thing to the Meridian of the Place in which they make their Observations. 1122

In explaining the Phænomena which relate to the several Parts of the Surface of the Earth, we shall consider the Observer going from the Pole

to the Equator; and first, only take notice of the diurnal Motion.

1123 *Plate* XXIII. *Fig.* 3.] When the Spectator is at S, in the very Pole of the Earth T, the celestial Equator E *e* coincides with the Horizon, and the Pole of the World P is in the *Zenith*; in that Case, because the Circles which are parallel to the Horizon, are also parallel to the Equator, all the heavenly Bodies appear to be carried by a Mo-
*1083 tion parallel to the Horizon, * in Circles which are represented by the Lines A *a*, B *b*. *The heavenly Bodies in the Hemisphere* E P *e never set, and*
1124 *the others are never visible. The Horizon in this Situation is said to be parallel, or this Situation is called a parallel Sphere.*

1125 *Plate* XXIII. *Fig.* 4.] *If an Observer* upon the Earth T *recedes from the Pole*, and is at S, *the Horizon is said to be oblique, or the Sphere is oblique*; then the Axis P *p* is inclin'd to the Horizon *b b*, so much the more as the Observer is farther from the Pole.

DEFINITION XVII.

1126 *The Angle which the Axis of the Earth makes with*
*1105 *the Horizon, is called* the Height of the Pole.*

1127 This *Height of the Pole is equal to the Latitude.*

The Height of the Pole is the Angle P T *b*, whose Measure is the Arc P *b*; the Latitude is measur'd by an Arc, which upon the Earth cor-
*1118 responds to the Arc Z E in the Heavens; * but it is equal to the Arc P *b*; for the Complement of each of them, to a Quarter of a Circle, is the Arc Z P.

1128 *In this Position of the Observer*, because the Equator is inclin'd to the Horizon, *all the heavenly Bodies are carried by the diurnal Motion in Circles inclined to the Horizon*, represented by the Lines A *a*, B *b*.

Some

Some of the heavenly Bodies rise and set at every 1129
Revolution of the Earth; namely, those which are between the Parallels to the Equator B *b* and *b i*, because all the Parallels between those two are cut by the Horizon.

The Planes of the Equator and the Horizon go thro' the Center of the Earth, therefore these Circles cut one another mutually into two equal Parts, and half of the Equator is above the Horizon; therefore *the heavenly Bodies which are in* 1130
*the Equator, are above the Horizon during half a Revolution of the Earth about its Axis**; and on *1081
account of the Equability of the Motion about the Axis, *are invisible during an equal Time.*

These also rise due East, and set due West (that is, 1131
in the very Points of the East and West) for the Section of the Planes of the Equator and the Horizon is perpendicular to a Plane perpendicular to both these Planes, and this last Plane is the Plane of the Meridian of the Place*; wherefore *1078
the above-mention'd Section is perpendicular to 1116
the Meridian Line*, and consequently goes thro' *1117
the East and West Points.* *1102

Bodies between the Equator and a Parallel B *b*, 1103
which touches the Horizon, as in the Circle A *a*, 1132
continue longer above than below the Horizon; *and this Difference is so much the greater, the more the* 1133
Circle A *a approaches that Pole which is above the Horizon*; on the contrary, *as the Body goes towards the opposite Pole, its Time of Continuance above the Horizon is the longer.*

This Inequality of the Time that a Body is above 1134
and below the Horizon, increases as the Height of the Pole does, because of the Diminution of the Angle made with the Horizon by the Equator and its Parallels.

Bodies whose Distance from the Pole is equal to the 1135
Height of it, never set; for such is the Distance of the

the Circle B b, which touches the Horizon, but has no Part of it below the Horizon.

Bodies less distant from the Pole do not so much as come down to the Horizon.

1136 It appears by the same Reasoning, that *Bodies whose Distance from the opposite Pole does not exceed the Height of the Pole*, never rise above the Horizon, and *are always invisible*.

1137 Bodies whose Distance E Z from the Equator is equal to the Height of the Pole, go thro' the Zenith Z; for E Z is equal to the Latitude of the Place to which the Height of the Pole is
*1126 equal *.

1138 *Plate* XXIII. *Fig.* 5.] *When a Spectator* S has receded as far as he can from the Pole, he *comes to the Equator*, whose Points are equally distant
1075 from each Pole; then the Axis P p is in the Ho-
1114 rizon, with which the Equator makes a right An-
1075 gle, for which reason the *Horizon is said to be*
1114 *right*, or this is called a *right Sphere*.

The Horizon cuts into two equal Parts all the Circles that are parallel to the Equator, which are represented by the Lines A a, B b; therefore
1139 *all the heavenly Bodies, at every Revolution of the Earth, rise and set, and are visible and invisible during equal Times.*

1140 *The Æquator itself goes thro' the Zenith, and therefore all the Bodies that are in it pass thro' it also.*

If what we have explain'd concerning the diurnal Motion, be applied to the Bodies of whose other apparent Motions we have spoken before, the Phænomena will be easily determin'd from the Motions join'd together; those that relate to the Sun are more remarkable than the rest, and therefore more particularly to be explain'd.

DEFI-

DEFINITION XVIII.

We call a natural Day the Time elapsed between 1141
the Recess of the Sun from the Meridian of a Place, and its next Return to the same Meridian.

This Day differs from the Time of the Revolution 1142
of the Earth about its Axis, which Times would be equal if the Sun appear'd immovable among the fixed Stars; but whilst by the diurnal Motion, in the Time of one Revolution of the Earth about its Axis, the Sun is carried round from East to West, that is, *in antecedentia**, it is carried by a *1080
contrary Motion in the Ecliptic *, whereby it * 996
comes later to the Meridian.

But as the Sun does not every Day go thro' an 1143
equal Space in the Ecliptic*, all the *natural Days* * 997
do not equally exceed the Revolution of the Earth about its Axis; therefore these Days are *unequal to one another*.

Natural Days are unequal also upon another Account, namely, by reason of the Inclination of the Ecliptic in respect to the Equator; whence it follows, that the annual Course of the Sun is unequally inclin'd to the Equator in different Points; and tho' the Sun should equally go forward every Day in the Ecliptic, the natural Days would not equally exceed the Time of the Revolution about the Axis; for if the Motion of the Sun be resolved into two Motions*, of which the one is paral- * 192
lel to the Equator, and the other perpendicular to it, the first is only to be consider'd in determining the Excess above-mention'd; and that it is unequal, is plain from the different Inclination above-mention'd.

These two Causes of Inequality often concur, and often act contrariwise.

Every natural Day is divided into 24 equal Parts, 1144
which are called Hours; each Hour is divided into

60 *Minutes, and each Minute into* 60 *second Minutes, or Seconds; and so on.* That *these Parts of Time vary in different Days,* appears plainly from
*1143 what has been * said; they are by Astronomers reduc'd to Equality, by considering the Number of Hours in the whole Revolution of the Sun in the Ecliptic, and dividing the whole Time into as many equal Parts as there are Hours, 24 of
1145 which are taken for one Day. *The Time, whose Parts are* by this Method *reduc'd to Equality, is called mean Time; and that Reduction is called the Æquation of Time.*

1146 *We always make use of the Days and Hours of the mean Time in determining the Periods of the heavenly Motions.*

Definition XIX.

1147 The artificial Day *is the Time that the Sun stays above the Horizon.*

1148 We always speak of it when we mention Day in opposition to Night. *In determining the Length of artificial Days, we shall not attend to the Equation of Time.*

1149 *The* Crepusculum *always comes before the Sun's*
1150 *Rise, and follows its setting; this is that dim Light which we commonly call Morning and Evening* Twilight.

1151 *The Twilight is produc'd by the Atmosphere, which is enlighten'd by the Sun's Rays, and whose Particles reflect the Light* every way; from whence some Rays come *to us, tho' the Sun be depressed* 18 *Degrees below the Horizon.*

1152 *In the parallel Sphere,* that is, to all those that
*1138 dwell under the Æquator, * *the Days and Nights*
*1139 *are equal to one another all the Year round**, and are
1144 of 12 Hours.

1153 *In the oblique Sphere the Days are longer or shorter, according to the different distance of the Sun from the*

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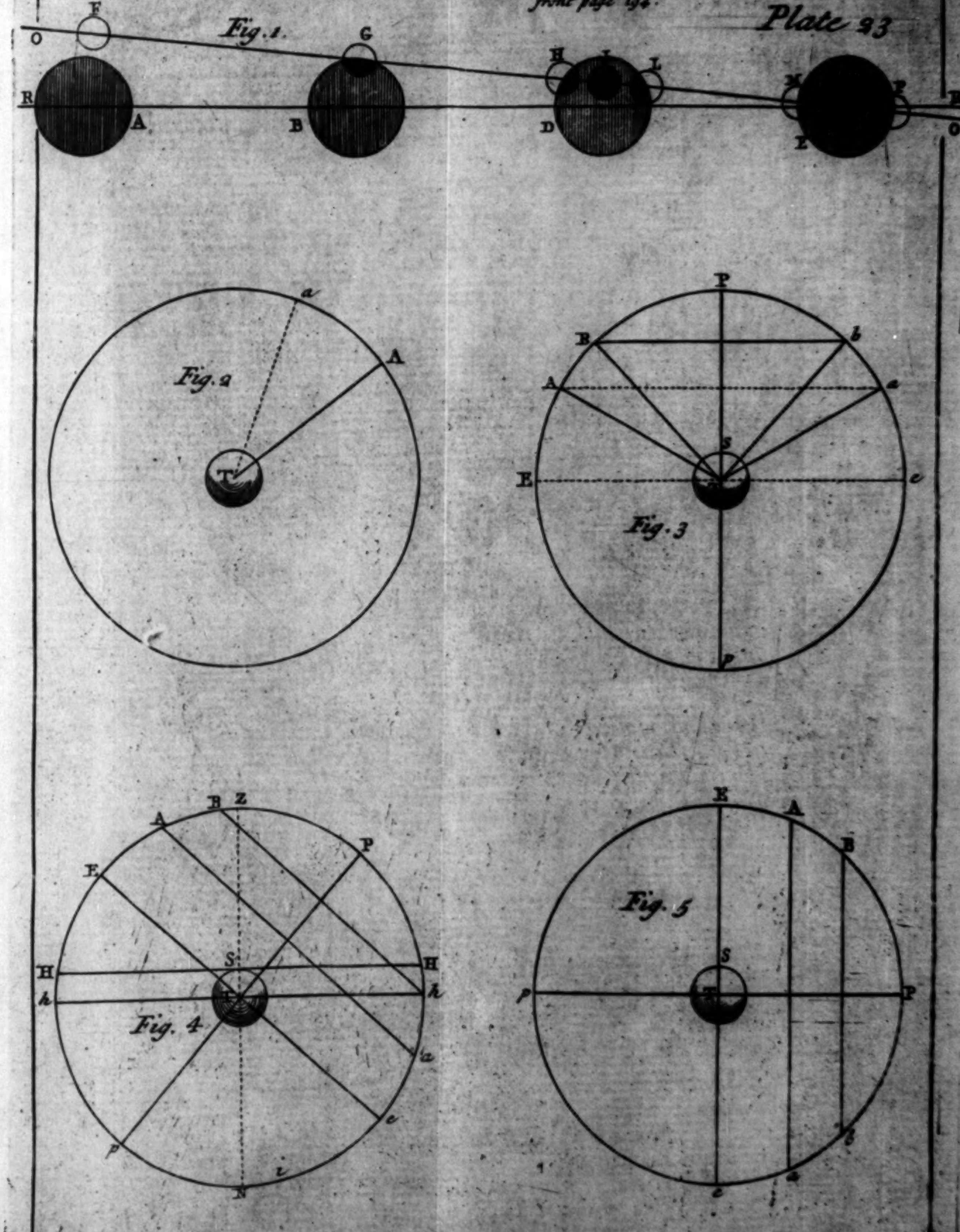
Plate 23



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*Equator towards either Pole** ; for the Sun recedes *1131
from the Equator towards the Poles 23 Deg. *1132 *1087
29 Min.* 1088

The Sun is in the Equator about the 11th of March 1154
and the 12th of September, *and then the Day is*
*equal to the Night**, *which happens all over the Earth*, *1194
except just at the Poles.

DEFINITION XX.

Those Points of the Ecliptic, in which it is cut by 1155
*the Equator**, *are called the* Equinoctial Points, *1085
because the Sun is in those Points when the above
mention'd Equality of Day and Night happens.

DEFINITION XXI.

These Points of the Ecliptic, in which the Tropics
*touch that Circle**, *are called the* Solsticial Points ; *1089
because for a few Days, when the Sun comes to
those Points, and goes beyond them, it does not
sensibly change its Declination, and the Length
of the Days not sensibly vary.

Under the Poles, if there be any Inhabitants there, 1156
they can only once in a Year see the rising and
the setting Sun, and *only one Day with one Night*
make up their whole Year ; the Sun continues above
the Horizon all the while it goes thro' one half of
the Ecliptic*, the rest of the Time it is hid under *1085
the Horizon ; but yet *their Day is lengthen'd upon* 1123
*account of the Refraction** ; *and the Twilights last* 1157 *1113
very long, for they last as long as the Declination
of the Sun towards the hidden Pole does not
exceed 18 Degrees*. *1151

At the Arctic Pole, in the first six Signs, from 1158
Aries to *Libra*, the Sun is above the Horizon ;
therefore at that Pole *the Day exceeds the Night* 9
*natural Days**, *besides the Diminution of the Night* *1000
*on account of the Refraction**. *1157

These general things which relate to the diffe-
rent Positions of the Horizon being explained,
some more particular things are to be examin'd.

1159 *The whole Surface of the Earth is divided into five*
Zones, the first *is contain'd between the two Tropics*
1160 T T *t t* (Plate XXIV. Fig. 2.) *and called the*
torrid Zone. *There are* two temperate Zones, *and*
two frigid Zones; the northern temperate Zone
is terminated by the Tropic of *Cancer* T T and the
1161 arctic polar Circle A A; the southern temperate
Zone *is contain'd* between *t t*, the Tropic of *Ca-*
1162 *pricorn*, and the polar Circle *a a*; *the frigid Zones*
are circumscrib'd by the polar Circles, and the Poles
are in the Centers of them.

1163 *In the torrid Zone, twice a Year, the Sun goes thro'*
*1137 *the Zenith at Noon**; for the Elevation of the
1160 Pole is less than 23 Deg. 29 Min. and the di-
1127 stance of the Sun from the Equator towards the
Pole, which is above the Horizon, is twice in a
1087 Year equal to the height of the Pole; for which
1088 reason also in the Limits of that Zone, namely,
1164 *under the Tropics, the Sun comes to the Zenith only*
*1087 *once in a whole Year**.

1089 *In the temperate and frigid Zones* the least height
1165 of the Pole exceeds the greatest distance of the
1087 Sun from the Equator, and therefore to their
1162 Inhabitants *the Sun never goes thro' the Zenith**;
1162 1166 yet *the same Day the Sun rises to a greater height, the*
less the height of the Pole is, because thereby the
*1137 Inclination of the Circles of the diurnal Motion
with the Horizon is less.

1167 *In the torrid Zone, and in the temperate Zones,*
*1129 *every natural Day the Sun rises and sets*, for the di-
1137 1168 stance of the Sun from the Pole always exceeds
1087 the height of the Pole; yet *every where, but un-*
1160 *der the Equator**, *the artificial Days are unequal to*
1161 *one another**; which Inequality is so much the
1152 greater, the less the Place is distant from a frigid
*1132 *1134 Zone*.

But *in the polar Circles*, just where the tempe- 1169
rate Zones are separated from the frigid ones, the height of the Pole is equal to the distance of the Sun from the Pole when it is in the neighbouring Tropic*; and therefore in that Case, that is, *once* *1089
a Year, the Sun in its diurnal Motion performs one 1091
entire Revolution without going down under the Horizon.

But *every where in a frozen Zone* the height of 1170
the Pole is greater than the least distance of the Sun from the Pole*; therefore *during some Revo-* *1089
lutions of the Earth, the Sun is at a distance from 1162
the Pole which is less than the Pole's height, and during all that time it *does not set*, nor so much as touch the Horizon*; but where the distance *1135
from the Pole, as the Sun recedes from it, does exceed the height of the Pole or Latitude of the Place*, the Sun rises or sets every natural Day*; *1127 *1129
then in its Motion towards the opposite Pole, *it*
stays in the same manner below the Horizon, as was 1171
said of the Motion *above the Horizon**. *1136

These Times, in which the Sun makes entire Revolutions above the Horizon and below it, in its diurnal Motion, are so much the greater; that is, *the longest Day and Night last the longest, the less*
the Place in the frigid Zone is distant from the Pole, 1172
till at last, at the Pole itself, they take up the Time of the whole Year.

From the same Causes, namely, the Obliquity of the Ecliptic in respect of the Equator, by which are occasion'd all the things which relate to the Inequality of Days, which is different in different Places, we also deduce the difference of Seasons which succeed one another every Year: I shall speak of them first in respect to the frigid and temperate Zones, and then in respect to the torrid Zone.

The Rays of the Sun communicate Heat to the Air, not only when they come directly from the Sun, but when they are reflected irregularly from
* 582 Bodies or the Surface of the Earth *.

This Effect is so much greater as the Rays strike the less obliquely against the Surface of the Earth, and that upon a double Account. 1. If you resolve the Motion of the Light into two
* 192 Motions *, one of which is parallel, and the other perpendicular to the Surface of the Earth, the Light acts upon Bodies only by this last Motion, which diminishes as the Obliquity increases. 2. There are more Rays acting at one time upon the same Part of the Surface of the Earth, the more directly they come upon it.

1173 Hence we deduce, that *the Causes of Heat increase when the Days increase*, by the Sun coming towards the Pole, which is above the Horizon, because the Sun does daily ascend to a greater height; so that to the diminish'd Obliquity is added the longer Continuance of the Sun above the Horizon, both which concur to the increasing of the Heat; the Nights also are diminish'd as the Days increase, and the Height that is produc'd by Day has less Time to decrease in.

In the northern Zones, as follows from this, the Cause of the Heat is the greatest of all when the
*1090 Sun comes to the Tropic of *Cancer* *; *yet the*
1174 *Heat is not always the greatest where the Cause of Heat is the greatest*, for the Heat increases as long as that which is acquir'd by Day is not wholly destroy'd by Night; for tho' the daily Augmentations be diminish'd, as long as there is an Aug-
1175 mentation the Heat increases. The most intense Cold is not upon the shortest Day, in which the Obliquity of the Sun's Rays is the greatest, and the Absence of the Sun the longest; but the Cold increases as long as the Diminution of Heat does

does last; concerning which one may reason in the same manner as concerning the Increase of Heat.

The Year is divided into four Seasons, the hottest is called the Summer, the coldest the Winter; the temperate Season that follows the Winter, Spring; and the Autumn comes in between Summer and Winter. 1176

In the northern Regions, in the beginning of Spring the Sun appears to be in the beginning of Aries; *in the beginning of Summer the Sun comes to the Tropic of* Cancer; *when the Sun enters* Libra *the Autumn begins; in the beginning of Winter the Sun performs its diurnal Motion in the Tropic of* Capricorn; all which may be easily deduc'd from what has been explain'd*. 1177

*1174 *1175

In the southern Regions the Summer happens in the Time of the Winter above-mention'd, and they have their Spring whilst the former have their Autumn; and so of the other Seasons. 1178

The general Causes upon which the Division above-mention'd depends, are often disturb'd by Causes relating to particular Places, especially *in the torrid Zone*, of which we said we must treat separately; in most Places of this Zone *there are only two Seasons observ'd* (viz.) *Summer and Winter, which are chiefly distinguish'd by dry and wet Weather.* 1179

When the Sun comes to the Zenith of any Place there are almost continual Rains, upon which account the Heat is diminish'd, which *Time is referred to, or called Winter*; as the Sun recedes the Rains diminish, *the Heat is increas'd, and that Time is referr'd to Summer.* 1180 1181

*In the middle of the torrid Zone there are two Summers, and as many Winters, because the Sun comes up twice to the Zenith**. 1182

*1163

Towards the Sides of the Zone, tho' the Sun comes twice to the *Zenith*, yet ſince there is but a ſmall Time between its coming to it the firſt and ſecond time, both the Winters are confounded into one; wherefore only two Seaſons in a Year are obſerv'd there.

CHAP. IX.

Concerning the Phænomena ariſing from the Motion of the Axis of the Earth.

WE have ſaid that the Axis of the Earth is
* 952 carried by a parallel Motion *; we have not conſider'd a ſmall Motion, whereby it is really moved, of which we ſhall now ſpeak.

The Axis of the Earth keeping the Inclination of
1183 66 Deg. 31 Min. *to the Plane of the Ecliptic, revolves in* antecedentia; that is, is ſucceſſively car-
1184 ried towards all Parts; and its Extremities (*viz.*) *the Poles of the World, deſcribe Circles round the Poles of the Ecliptic,* from Eaſt to Weſt; and *this Revolution is perform'd in the Time of about* 25000 *Years*; *which Period is called* the great Year.

Becauſe the Earth is look'd upon as immoveable by its Inhabitants, this Motion is referr'd to the heavenly Bodies, as has been ſaid of the other Motions; therefore whilſt the Poles of the World are mov'd about the Poles of the Ecliptic in *antecedentia*, and paſs ſucceſſively thro' all the Points, that are 23 Deg. 29 Minutes diſtant from theſe Poles, theſe Points themſelves, or rather the fixed Stars that are in them, come towards the Poles of the World ſucceſſively, and ſeem to be carried in *conſequentia*, and to deſcribe Circles which are really

really describ'd by the Poles of the World about the Poles of the Ecliptic, which being placed in Centers, alone are at rest; for together with the Stars above-mention'd, the rest of the Stars (because they keep the same Situation in respect to one another) * do also appear to be mov'd. * 923

Therefore *the* whole *Sphere of the fixed Stars* 1185
seems to move, in consequentia, *about an Axis passing thro' the Poles of the Ecliptic*, and each Star apparently describes a Circle parallel to the Ecliptic; by which Motion the Latitude of the Stars is not chang'd.

The Plane of the Equator makes a right Angle with the Axis of the Earth, therefore by the aforesaid Motion of its Axis, the Section of the Plane of the Equator, with the Plane of the 1186
Ecliptic, is mov'd round; wherefore *the first Points of* Aries *and* Libra *, which are always *1085
opposite, *move thro' the whole Ecliptic Line in the Space of about* 25000 *in antecedentia*; yet they are look'd upon as immoveable by the Inhabitants of the Earth, who imagine that the fixed Stars themselves are mov'd *in consequentia* *. *1185

CHAP. X.

Concerning the fixed Stars.

WE have said that the fixed Stars are lucid Bodies, removed so far off, that their Distances can be compar'd with no Distances in the planetary System; for *Astronomers have not* 1187
been able, by their nicest Observations, to observe the Poles of the World carried out of their Place in the annual

annual Motion of the Earth, altho' they describe Circles in the Heavens which are equal to the
* 952 Earth's Orbit.*

DEFINITION I.

1188 This Motion of the Pole is called the *annual Parallax.*

That the fixed Stars are at an immense distance, is also prov'd by Observations with the help of
1189 Telescopes; *if any fixed Star*, even the lucid and conspicuous, *be beheld with a Telescope*, thro' which the Diameter of the Sun would appear equal to the Diameter of the Earth's annual Orbit, *it will appear to be a lucid Point, without any sensible Magnitude*; for all the fixed Stars appear less when they are seen thro' Telescopes, than they do to the naked Eye; for it is only their twinkling which makes them appear to have any sensible Magnitude.

1190 *That the Stars may be distinguish'd, they are referr'd to various Figures, which are imagin'd in the Heavens, and are called Constellations.*

1191 *Twelve Constellations are imagin'd to be in the Zodiac, which are called the Signs of the Zodiac*; they receive their Names from the Animals or Things
1192 which they represent: *Aries*, *Taurus*, *Gemini*, *Cancer*, *Leo*, *Virgo*, *Libra*, *Scorpius*, *Sagittarius*, *Capricornus*, *Aquarius*, *Pisces*. These Signs have given their Names to 12 Parts of the Ecliptic, of
* 999 which we have spoken before*.

In the Time of *Hipparchus*, the Sections of the Ecliptic and Equator were between the Constellations of *Pisces* and *Aries*, and *Virgo* and *Libra*; and the Constellations gave their Names to those Parts of the Ecliptic which passed thro' each
1193 Constellation; *and the Parts of the Ecliptic, supposing the beginning of* Aries *and* Libra *in the Intersections*

ctions of the Equator and the Ecliptic, have kept the Names which they had at that time, *tho' these Intersections be carry'd from their old Places** ; whence *1186 the *Sun* is said to be in *Taurus* when it moves among the Stars of the Constellation *Aries*.

The Zodiac separates the North Part of the Heavens from the South Part.

1194 *In the northern Region are the following Constellations : the lesser Bear, the greater Bear, the Dragon, Cepheus, the Hounds, Bootes, the northern Crown, Hercules, the Harp, the Swan, the Lizard, Cassiopeia, Camelopardus, Perseus, Andromeda, the Triangle, the lesser Triangle, the Fly, Auriga, Pegasus, or the Flying-horse, Equuleus, the Dolphin, the Fox, the Goose, the Arrow, the Eagle, Antinous, Sobiesky's Shield, Serpentarius, the Serpent, Mount Mænalus, Berenice's Hair, the lesser Lion, the Lynx.*

1195 *In the southern Region of the Heavens are the following Constellations, many of which are invisible to us ; * namely, the Whale, the River Eridanus, the* *1131 *Hare, Orion, the great Dog, Rhinoceros, the lesser Dog, the Ship Argo, Hydra, the Sextant of Urania, the Cup, the Crow, the Centaur, the Wolf, the Altar, the southern Crown, the southern Fish, the Phænix, the Crane, the Indian, the Peacock, the Bird of Paradise, the southern Triangle, the Cross, the Fly, the Chamæleon, King* Charles's *Oak, the Flying-fish, the* Toucan, *or* American *Goose, Hydrus, or the* Water-Serpent, *Xiphias, or the* Sword-fish.

Definition II.

1196 *The Stars which are between the Constellations are called* unform'd Stars.

1197 *The Stars are not equally lucid, and they are referr'd by* Astronomers *to six Classes* ; the most lucid are

are called Stars of the first Magnitude, others are said to be Stars of the second Magnitude, others of the third, &c. to the sixth Magnitude.

1198 *Some are not referr'd even to this last Class, and are called* nebulous Stars.

1199 *There is also a certain* Zone *or* Belt *observ'd in the Heavens,* which is not every where of the same Breadth, and goes round the whole Heavens, and in some Places is separated, so as to become dou-
1200 ble; from its Colour it is called *the milky Way*; it is plain from Observations, by the help of the Telescope, that this Way is *an Assemblage of innumerable fixed Stars, which cannot be seen by the naked Eye,* either because they are less than the other Stars, or more distant.

1201 *Towards the Antarctic Pole there are two* Nubeculæ, *of the same Colour as the milky Way, which are also Heaps of small Stars,* and cannot be seen without a Telescope; besides the Stars which are observ'd in these *Nubeculæ*, and in the *milky Way*,
1202 *to whatsoever Part of the Heavens you point the Telescope, you may discover small Stars in a great Number, which are not visible to the naked Eye*; very often an Heap of Stars appears to the naked Eye to be but one Star.

1203 *Among the Stars, some are visible and invisible by Fits, and observe regular Periods*; others are successively sometimes more lucid, sometimes of a duller Light, and to be seen only by the help of a Telescope, and that at certain Times.

1204 *Yet they are not equally bright at every Period; sometimes Stars have appear'd suddenly exceeding the brightest in Light, which afterwards successively decreasing, have vanish'd in a short time, and still remain invisible.*

1205 Besides the Stars, *we observe in the Heavens several whitish Spots, which are in some measure lucid, and*

and invisible to the naked Eye; their Light is referr'd to the Stars which are in them, or they are look'd upon as nebulous Stars.

What these Spots are, cannot be determin'd; perhaps they are a Congeries of Stars, which have the same relation to the telescopic Stars, as those which form the *milky Way* have to those which are seen to the naked Eye.

4 AP 64

BOOK

BOOK IV.

PART II.

The PHYSICAL CAUSES of the Celestial Motions.

CHAP. XI.

Concerning universal Gravity.

HAving explained the Motions of the heavenly Bodies, and the Phænomena arising from them, we must now examine by what Laws these Motions are performed.

We have before laid down the Laws according
* 124 to which the Motions of Bodies are directed*;
125 if we add one to these, we shall see the whole
126 Contrivance by which that vast Machine, the
Planetary System, is governed.

1206 The Law to be added to the rest is this: *All Bodies are mutually heavy* (or gravitate) *towards*
1207 *each other; this Gravity is proportional to the Quantity*
1208 *of Matter; at unequal Distances it is inversly as*
the

the Square of the Distance; that is, all Bodies mutually attract, or tend towards each other, with the Force which belongs to each Particle of Matter acting upon each Particle; and the Force with which a Body acts upon others, is compounded of the joint Forces of all the Particles of which the Body consists; so this Force increases in the same Proportion as the Quantity of Matter, and is unchangeable in every Particle; it is always the same at the same distance; but the distance increasing, the Force decreases as the Square of the distance increases.

We call this Force Gravity, when we consider a 1209
Body which of itself tends towards another; because this Force is called by this Name near the Earth's Surface*. * 73

But when we consider a Body towards which ano- 1210
ther tends, we call this Force Attraction; we mean the same Effect by these Names, and nothing but the Effect; for since all Gravity is reciprocal*, * 126
it is the same to say, all Bodies gravitate mutually towards one another, as that Bodies mutually attract one another, or mutually tend towards each other.

We look upon this Effect as a Law of Nature*, because it is constant, and its Cause is un- * 74
known to us, and cannot be deduc'd from Laws that are known, as we shall shew by and by. Now that there is such a Gravity, is to be prov'd from Phænomena.

All the primary Planets are kept in their Orbits by Forces, which tend towards the Center of the Sun*; therefore there is a Force by which * 944
the Planets are carried towards the Sun, and 226
whereby the Sun tends reciprocally towards each of them*; *that is, the Sun and Planets gravitate* 1211
mutually towards each other. * 126

After

1212 After the same manner it is plain, that *the Sa-*
tellites of Jupiter *and* Saturn *gravitate towards each*
* 966 *other*; *as also that the Satellites of* Saturn *gravitate*
226 *towards their primary Planet*, *and that towards*
126 *them* *.
1213 *The Moon and the Earth also gravitate towards*
* 966 *each other* *.
226
126 *All the secondary Planets gravitate towards the*
1214 *Sun*, for they are all carried by a regular Motion
about their primary Planets, as if the primary
Planets were at rest; whence it is plain, that they
are carried about by the common Motion with
the primary Planets; that is, that the same Force
by which the primary Planets are every Moment
carried towards the Sun, acts upon *the secondary*
ones, and that they *are carried towards the Sun with*
1215 *the same Celerity as the primary Planets*; even the
Irregularities of the secondary Planets, which are
so small as only to be sensible with respect to the
Moon, confirm this Gravity of the secondary
Planets towards the Sun; for we shall shew here-
after, that all the Irregularities are caused by the
Change of the Moon's Gravity towards the Sun
at a different distance; and because the Lines,
in which the Earth and Moon tend towards the
Sun, are not altogether parallel.

1216 From the Gravity of the secondary Planets
towards the Sun, it follows that *the Sun gravitates*
* 126 *towards them* *.

1217 In respect of the Gravitation of the primary
Planets towards one another, Astronomers have
observ'd, that *Saturn* changes its Way when it is
nearest to *Jupiter*, which is far the greatest of all
the Planets; so that it is plain from immediate
Observations, *that* Jupiter *and* Saturn *gravitate*
towards each other.

Jupiter

Jupiter also in this Case, as *Flamsteed* has ob- 1218
serv'd, disturbs the Motion of the Satellites of
Saturn, attracting them a little to itself; which
proves that these Satellites gravitate towards *Ju-*
piter, and *Jupiter* towards them. From all which
Considerations * compar'd together, it follows, *1211
that the 17 Bodies, of which the Planetary Sy- 1212 1213
stem is made up, mutually gravitate towards each 1214
other, altho' no immediate Observations can be 1216
made concerning the Gravitation of each particu- 1217
lar one towards the rest *. 1218 * 7

The second Part of the Law is *, that Gravity *1207
is proportional to the Quantity of Matter; that
is, that all the Particles of Matter gravitate to-
wards each other; and therefore that the Law of
Gravity is universal, and that every Body acts
upon all other Bodies; which is deduc'd from
Phænomena.

The Forces of Gravity are as the Qualities of 1219
Motion which they generate *, and these Quan- * 58
tities, in unequal Bodies that are equally swift,
are to one another as the Quantities of Matter;
therefore since unequal Bodies, at the same di- * 62
stance from the attracting Body, move equally
swift by Gravity *, it is evident that the Forces *1215
of Gravity are proportional to the Quantity of
Matter; we find the same in all Bodies *near the* 1220
Earth's Surface, which have a Gravitation to-
wards the Earth, proportional to their Quantity
of Matter *; but *the mutual Gravity of all these* * 79
Bodies towards one another is not sensible, because it
is exceeding small in respect of their Gravity to-
wards the Earth, and therefore cannot disturb
their Motion arising from their Gravity towards
the Earth *, at least so as to make any sensible * 190
Change in the Direction of their Motions.

We shall presently shew, by another Method, that this universal Gravity of all the Particles of Matter, whereby they act upon one another, may
1222 be prov'd from Phænomena.

The third Part of the Law which we examine is, that Gravity decreases when the Distance increases, and is inversly as the Square of the Distances, which also follows from Phænomena.

1221 Bodies upon which Gravity acts according to
their Quantity of Matter, as in our System, are
mov'd with an equal Celerity in the same Circum-
stances, as we said before; so that it is no matter
whether the Bodies are greater or less, and they
are mov'd as if they were equal; but in this Case,
if the Force towards a Point decreases in an in-
verse Ratio of the Square of the distance from
that Point, and the Bodies move at various Di-
stances from it, and are kept in Circles by that
Force, the Squares of the periodical Times will
* 239 be to one another as the Cubes of the Distances*,
which is demonstrated by Geometers to obtain
(in respect of the mean Distances) in elliptic Lines,
whose Forces are directed to their Foci; but this
is the Case in Bodies which revolve about the *Sun*,
* 974 *Saturn*, and *Jupiter**; whence it follows, that
the Force of Gravity receding from the Centers
of these Bodies, decreases in an inverse Ratio of
the Squares of the Distances.

1222 By this Reasoning, supposing Gravity proportional to the Quantity of Matter, we demonstrate that it decreases in an inverse Ratio of the Square of the distance; and by the same Reasoning, supposing the Diminution of Gravity to be in this Proportion, it follows that Gravity is proportional to the Quantity of Matter; as is very evident.

But we prove by another Argument, that the Diminution of Gravity, so often mention'd, is in

an inverſe Ratio of the Square of the Diſtance; ſo that there can remain no Doubt concerning the two Laws of Gravity, which we now treat of.

The Planets are mov'd in Orbits at reſt *, and *1223
are kept in them by Forces, which are directed * 929
to an eccentric Point *; but it is plain that this * 931
would not obtain, if the central Force did not
increaſe in an inverſe Ratio of the Square of the * 241
Diſtance *. 243

It follows from the ſame Reaſoning, that rece- 1224
ding from the Center of the Earth, Gravity decreaſes, according to the ſame Law; for the Moon is retain'd in its Orbit by a Force which tends towards the Center of the Earth, that is, to
an eccentric Point *; and tho' the Line of the * 967
Apſides is not carried by a parallel Motion, its 966
Agitation is ſo ſmall, if we conſider every Revo- 226
lution, that it may be look'd upon here as quieſcent; for if we compute the Force which keeps the Moon in its Orbit ſo agitated, we ſhall find the Diminution of the Force of Gravity, in reſpect of the Moon, to differ very little from an inverſe Ratio of the Square of the Diſtance; and we ſhall ſhew hereafter that this difference depends upon the Action of the Sun.

And no Doubt will remain concerning this Di- 1225
minution, if we conſider, *that the Moon is kept in its Orbit by that very Force wherewith Bodies are carried towards the Earth, near the Earth's Surface*; which is diminiſh'd, according to the Law of Diminution ſo often mention'd. The mean diſtance of the Moon is 60 $\frac{1}{2}$ Semidiameters of the Earth; we have before ſhewn that a Diameter of the
Earth contains 3400669 *Rhynland* Perches *; * 976
whence knowing the periodical Time, we eaſily diſcover that the Moon in one Minute of Time goes thro' 16425 $\frac{1}{2}$ *Rhynland* Perches of her Orbit; this Arc is not the hundredth Part of one

P 2 Degree,

Degree, and may be look'd upon as its Subtenſe, therefore the Diameter of its Orbit is to this Arc as the Arc itſelf is to its verſed Sine, which is diſcover'd to be of 15,736 *Rhynland* Feet, and it is the Space which the Moon and Earth would go thro' in one Minute, coming to one another by their mutual Attraction. The Celerity with which a Body comes to another by the Force of Gravity, depends upon the Force with which it is attracted by that other, all whoſe Particles of Matter attract it; therefore the Celerities of the Moon and Earth, as they come towards each other, are inverſly as the Quantities of Matter in them, which is alſo deduc'd from the equal

* 126 Quantity of Motion that is in each Body*; there-

65 fore by this Proportion we diſcover how much of the aforeſaid Space (15,736 Feet) is gone thro' by the Moon; as the Quantity of Matter in both Bodies is to the Quantity of Matter in the Earth, ſo is the Space gone thro' by both Bodies in their mutual Acceſs towards each other to the Way gone thro' by the Moon only. The Quantities of Matter in the Moon and in the Earth, as we ſhall ſhew hereafter, are to one another as 1 to 39, 37; and 40, 37 is to 39, 37 as 15,736 to 15, 344, the Space gone thro' by the Moon; which therefore would be gone thro' in one Minute by any Body, which at the Moon's diſtance ſhould be impell'd by Gravity towards the Earth; this Force increaſing in an inverſe Ratio of the Square of the diſtance from the Center, the Space gone thro' in the ſame time at the diſtance of a Semidiameter of the Earth, that is, on its Surface, will be $60^{\prime} \times 60\frac{1}{2} \times 15{,}344$ (*viz.*) 56158 Feet; but becauſe in every Motion equably accelerated, as here (for we conſider the Force as remov'd from the Earth's Center to the diſtance of its Surface) the Squares of the times are as the Spaces gone

thro' in the Fall *, by dividing the Number by * 131
60 x 60, that is, 3600, we have the Space gone thro' by a Body in one Second near the Earth's Surface, by the Force with which the Moon is kept in its Orbit, which is discover'd to be 15,6. *Rhynland* Feet.

Now if we examine the Gravity which we daily find in all Bodies near the Earth's Surface *, it * 72
is plain from what has been said concerning the Motion of Pendulums *, and from Experiments * 157
made upon Pendulums, that a Body in falling 158
goes thro' 15,6. *Rhynland* Feet in one Second of Time, and therefore falls with the Force by which the Moon is kept in its Orbit.

In this Computation we have neglected to consider the Action of the Sun, because it is small, and sometimes increases, sometimes diminishes the Gravity of the Moon towards the Earth.

We have consider'd the Centers of the Bodies in examining the Law of the Diminution of Gravity, altho' Gravity belongs to all the Particles of Bodies; because it is plain by mathematical Demonstration, that *the Action of a spherical Body*
(in which, in every Part, the Particles, that are 1226
equally distant from the Center, are homogeneous, and which is made up of Particles, towards which there is a Gravity that decreases, receding from each of them in an inverse Ratio of the Square of the distance) is directed towards the Center of the Body; and receding from it, is diminish'd in the same inverse Ratio of the Square of the distance; so that such a Body acts as if all the Matter of which it consists was collected in its Center; whence we deduce the following Conclusions.

That *on the Surfaces of Bodies, in which the Mat-* 1227
ter is homogeneous at equal Distances from the Center, the Gravity is directly as the Quantity of Matter, and inversly as the Square of the Diameter *; for in * 1207

1208 these Bodies the Distances from the Center are as the Diameters.

1228 That *on the Surfaces of Bodies that are spherical, homogeneous, and equal, the Gravities are as the Densities of the Bodies*; for the Distances from the Center are equal, in which Case the Forces of Gravity
1207 are as the Quantities of Matter, which in equal
* 228 Bodies are as their Densities*.

79 That *on the Surfaces of the Bodies that are spheri-*
1229 *cal, unequal, homogeneous, and equally dense, the Gra-*
*1208 *vities are* inversly as the Squares of the Diameters*, because the Distances from the Center are *in the*
*1207 *Ratio* of those Diameters*, the Gravities also are directly as the Cubes of their Diameters; for the Quantities of Matter in Spheres are in that Ratio; and the Ratio compounded of that direct Ratio of the Cubes of the Diameters, and the inverse Ratio of their Squares, in the direct Ratio *of the Diameters themselves*.

1230 Therefore *if both the Densities and the Diameters differ, the Gravities on the Surface will be in a Ratio*
*1228 *compounded of the Densities * and the Diameters**;
*1229 therefore dividing the Gravity on the Surface by
1231 the Diameter, you will have *the Density*; which consequently *is in a direct Ratio of the Gravity on the Surface, and an inverse Ratio of the Diameter.*

1232 *If a Body be plac'd in a Sphere that is homogeneous, hollow, and every where of the same thickness*, wheresoever it be placed *it has no Gravity*, the opposite Gravities mutually destroying one another pre-
1233 cisely; whence it follows, that *in an homogeneous Sphere* a Body coming towards the Center, gravitates towards the Center only from the Action of the Sphere, whose Semidiameter is the distance of the Body from the Center; which *Gravity decreases in coming towards the Center, in the Ratio of*
*1229 *the distance from the Center**; for all Matter, which is at a greater distance from the Center, forms an hollow

hollow Sphere, in which the ſeveral Actions on a Body deſtroy each other*. *1232

We have ſaid, that the Gravity which we have hitherto explain'd, is to be taken for a Law of Nature, becauſe we don't know the Cauſe of it, and becauſe it depends upon no Cauſe that is known to us; which will evidently appear, if we attend to what follows.

(Viz.) That *Gravity requires the Preſence of the attracting Body*; ſo the Satellites of *Jupiter*, *ex. gr.* 1234
gravitate towards *Jupiter*, whereſoever it be*. *1212

That *the diſtance remaining the ſame, the Celerity* 1235
*with which Bodies are carried by Gravity, depends upon the Quantity of Matter in the attracting Body** ; *1207
and that the Celerity is not chang'd, let the Maſs of 1236
*the gravitating Body be what it will**. *1207

Beſides that, *if Gravity depends upon any known* 1237
Law of Motion, it ought to be referr'd to a Stroke from an extraneous Body; *and* becauſe Gravity is continual, *a continual Stroke would be required.*

If there be ſuch a Sort of Matter continually ſtriking againſt Bodies, it muſt of neceſſity be fluid and very ſubtile, ſo as to penetrate all Bodies; for Bodies that are any how ſhut up in others are heavy.

Now let a Mathematician conſider, whether a Fluid ſo ſubtile as freely to penetrate the Pores of all Bodies, and ſo rare as not ſenſibly to hinder the Motion of Bodies (for in a Place void of Air the Motion of a Pendulum will be continu'd very long) can impel vaſt Bodies towards one another with ſo much Force; let him explain how this Force increaſes in a Ratio of the Maſs of the Body towards which another is carried*. *1235

Laſtly, let him ſhew, what ſeems moſt difficult to me, how all Bodies, in any Situation whatſoever (if the diſtance, and the Body towards which the Gravitation is, remain the ſame) are carried

1236 with the ſame Velocity; that is, how a Liquid, which can only act on the Surfaces either of the Bodies themſelves, or their internal Particles, to which it is not hinder'd from coming by the Interpoſition of other Particles, can communicate ſuch a Quantity of Motion to Bodies, which in all Bodies exactly follows the Proportion of the Quantity of Matter in them, and which in this Chapter we have prov'd to obtain every where in Gravity, and which we have demonſtrated by a direct Experiment, in reſpect of the Gravity near
* 77 the Earth's Surface*.

1238 Yet we don't ſay that *Gravity does not depend upon any Stroke*, but that it does not follow from that Stroke, *according to any Laws known to us*; and we confeſs that we are entirely ignorant of the Cauſe of Gravity.

CHAP. XII.

Of the celeſtial Matter; where a Vacuum *is proved.*

HAving explained the Laws whereby the whole planetary Syſtem is govern'd, ſeveral things muſt be firſt laid down before we proceed to the phyſical Explication of the Syſtem. We muſt begin, by ſaying ſomething of the celeſtial Matter, that is, of the Medium in which the Bodies that make up the Syſtem are mov'd; which would be done in few Words, if all Philoſophers agreed that there is a *Vacuum*.

We

We have before prov'd that a *Vacuum* is possible*, now we are to demonstrate that there is really one; *from only considering Motion we can deduce a Vacuum*, and this is a very common and usual way of proving it; to see the Force of which Argument, we must consider, that indeed all Motions are not impossible without a *Vacuum*, but most of those which are daily observ'd, which might be fully evinc'd by a longer Discussion; but it seems to me to be so evident from the following Consideration, that it would be useless to add much more. * 13 1239

The Figure of the least Particles is unchangeable, for the Particle whose Figure may be changed, consists of smaller Particles, which are moved in respect to each other; and therefore if it has a changeable Figure, it is not one of the least Parts.

But if the Figure of these Particles be unchangeable, and a Body can move between them, without such a Separation of the Particles as to leave a void Space, this will depend on the Figure of the Particles, and the Relation which they have to one another, which a Mathematician will not deny; therefore if keeping things in this State (as to their Figure and Relation) the Particles are increased, even in that Case Bodies may be mov'd without a *Vacuum*.

Now supposing the smallest Particles increas'd to the bigness of a cubic Foot, whatever be their Figure and Relation with the other Parts, which we suppose increas'd in the same Proportion as the first; let any one consider, whether Bodies of any bigness can be carried between those Parts in right Lines, and in all sorts of Curves, and yet never separate the Particles, so as to leave Vacuities between them?

We

We cannot conceive how the most subtile Parts are made, and therefore often attribute to them such Properties as do not follow from their Figure; but these Errors will be corrected by imagining the Particles increased.

1240 *We also prove a* Vacuum *by an Argument taken from Resistance.*

* 12 We have said that Matter is inactive*; some dispute about the Word, but no Man denies the thing; whence it follows, that a Body cannot move thro' a Fluid without undergoing a Resist-
* 319 ance*, and consequently a Retardation*. The
* 330 Resistance arising from the *Inertia* of the Matter (which Resistance alone is here consider'd) depends upon the Quantity of Matter to be remov'd out of its place, which is the same whether the Parts of a Fluid be greater or less, if the Celerity of the Body remains the same; whence it follows, that in determining what relates to the Resistance, we must have no regard to the Subtilty of the Fluid, as long as it cannot go thro' the Pores of Bodies; for if we come to such a Fineness of Parts, that a Fluid shall partly penetrate a Body, it will less resist the Body.

Now let us suppose any Ball or spheric Body to be mov'd along in a Medium of the same Density as itself, and so close, that the Parts of the Medium cannot pass thro' the Pores of the Body, this Body will be retarded every Moment; so that its Velocity at last will be reduc'd to half (as may be prov'd by a mathematical Demonstration) before the Body has gone thro' twice the Length of its Diameter.

In order to apply this Proposition to a Motion in a very subtile Fluid, which freely penetrates the Pores of all Bodies, and fills all Places, we must conceive a spherical Body without any Pores at all; and that such a Body may be supposed, by

by imagining all the Particles of Matter closely join'd, no Body will deny.

That the Resistance of such a Body in any Fluid does not depend upon the Bigness of the Parts of the Fluid, and is the same, whether the Parts of the Fluid be equal, or any how unequal, is evident.

If every thing be full of Matter, this Body can only move thro' a Fluid of the same Density as itself, for it must run against all the Matter which is in those Places thro' which it passes; and in them the Matter is without Interstices, as it is in the Body; therefore it will lose half its Velocity before it has run thro' the Length of twice its Diameter.

Now let us suppose the Body to be increas'd, the Quantity of Matter remaining the same, and the Body continuing homogeneous; that is, let there be Pores in the Body, thro' which the most subtile Particles of Matter may pass very freely, and let these Pores be equally dispersed all over the Body; if the Body thus chang'd be mov'd, the very subtile Fluid, of which we speak, will not run against the whole Surface, but only those Parts of the Surface which are between the Pores; which Parts being taken together, because we suppose the Body homogeneous, are equal to the Surface of the Body in the first Supposition, when we conceiv'd it to be without Pores; for the Body being increas'd, the Surface has not been changed, but only dilated by the Interposition of Pores; so that in both Cases the Body will undergo the same Resistance from the Impulse upon the Surface, and the Resistance on the dilated Body is greater, from the Fluid running against the internal Parts of the Body; wherefore this Body will sooner lose half its Motion in the second than in the first Case, that is, before it has

run

run thro' the Length of two Diameters of the first supposed Bigness; and therefore it loses a greater Quantity of Motion in going thro' two Diameters of the Bigness supposed in the second Case.

But this is contrary to Experience; for a homogeneous Ball of Gold, or Lead, &c. loses a much less Quantity of Motion than what we have mention'd in Water or Air; whence it follows, that the Supposition that all Things are full of Matter, is false; therefore there is a *Vacuum*.

1241 *That there is a* Vacuum, *does also agree with the Phænomena relating to Gravity*; by which it follows, that it is proportional to the Quantity of Matter; if all was full of Matter, Gravity would act equally every way, and the Forces which are directed towards opposite Parts, would destroy one another; and therefore no sensible Gravity would be observ'd, which is contrary to Experience.

These being premised, we must return to the celestial Matter.

1242 The Motions of the heavenly Bodies do not depend upon the Motion of the celestial Matter, if
1238 there be such a Matter; *whereby is overthrown the Opinion of those which say that the heavenly Bodies are carried along by the common Motion of the Matter which fills our System.* This Opinion is also overthrown by the Motion of the Comets; if there was a Medium in the System which carried about the Planets in its Motion, and also the Comets, it would at least sensibly disturb these last in their Motions, whilst they come almost directly towards the Sun, or directly recede from it, or are carried in *antecedentia*, that is, in a Motion contrary to the Motion of that Matter; now as this Motion is not disturb'd, but follows the Way which depends upon Gravity, as it is observ'd,

it

it is plain, that if there be any celeſtial Matter, and that it is in motion, it does not exert a ſenſible Action on the Bodies of the planetary Syſtem, which is alſo deduc'd from the ſmall Reſiſtance of ſuch a Medium; for by comparing the moſt ancient Obſervations with the modern, it does not appear that the Planets are ſenſibly retarded in their Motions: Yet in Air the Reſiſtance is ſenſible, wherefore the Denſity of the Medium, in which the Planets ſhould move, muſt be almoſt immenſely leſs; therefore *the planetary* 1243
Syſtem is not filled, unleſs it be *by* ſuch *a ſubtile Medium.*

But we may from the Diviſibility of Matter deduce, that a Quantity of Matter, how ſmall ſoever it be, may be diſperſed all over the planetary Syſtem, leaving but very ſmall Interſtices*. * 29

CHAP. XIII.

Concerning the Motion of the Earth.

BEſides the Queſtion that has been handled in the foregoing Chapter, there is alſo another to be examin'd, before we proceed to the Explication of the whole Syſtem.

That no Doubt may be made concerning the Syſtem, which has been explained in the firſt Chapter of this Book, we muſt here prove the Motion of the Earth, concerning which it is no Wonder that many have doubted; for the celeſtial Motions cannot be determin'd by us, but by Obſervations made by Obſervers on the Earth, and

and the ſame Phænomena appear, whether the Bodies themſelves be moved, or the Spectator be
* 993 moved*; ſo that it is not to be prov'd by immediate Obſervations, whether the Motion of the Earth is to be referr'd to the heavenly Bodies or not.

1244 *That the Earth is carried about the Sun, is deduced from the Analogy of the Motions, and from an Examen of the Laws of Nature.*

As to what relates to the Analogy of the Motions, it is to be obſerv'd, that Satellites revolve about *Jupiter* and *Saturn*, which are leſs than the central Body; that the Moon revolves about the Earth, than which it is leſs: laſtly, that the Sun has revolving about it leſs Bodies than itſelf, as *Mercury*, *Venus*, *Mars*, *Jupiter*, and *Saturn*; now if the Earth revolves with the reſt, then every
1245 where *in our Syſtem the leſſer Bodies move about the greater:* Now *there would be an Exception in this Rule, in reſpect of the Sun, if that* vaſt Body *was*
* 975 *to go round ſo ſmall a Body as the Earth**.

About the Sun *Jupiter* and *Saturn*, about which ſeveral *Bodies* revolve, *thoſe move the ſloweſt which*
1246 *are moſt diſtant from the central Body*, and according to this Rule, that the Squares of the periodical Times follow the Ratio of the Cubes of the
* 974 Diſtances*; *which Rule* may be applied to the Earth, if it be carried about the Sun with the reſt of the Planets, as appears, if its periodical Time (namely, the Time in which the Sun appears to perform an entire Revolution) and its Diſtance from the Sun be compared with the Diſtances and periodical Times of the reſt of the Planets.

Now this Rule *has only one Exception*; *if the Sun be mov'd about, the Earth is at reſt*; in this Caſe *Mercury*, *Venus*, *Mars*, *Jupiter* and *Saturn*, are ſubject to this Rule in their Motions, as alſo the five

five Satellites of *Saturn*, and the four Planets that accompany *Jupiter*, only the Moon and the Sun would move above the Earth in a Proportion quite different, and then the Celerity of the Sun would not only be greater than is required by this Law, but its Velocity would at leaſt be 26 times greater than that of the Moon, tho' it be remov'd to a vaſt diſtance from the Earth in reſpect to the Moon's diſtance; and therefore in this reſpect the Analogy of the celeſtial Motions would be diſturb'd.

To theſe Arguments I ſhall add others, whereby it will clearly appear, that the Motion of the Earth is a neceſſary Conſequence of the Laws of Nature, which are deduc'd from Phænomena.

All Bodies gravitate towards one another*, 1247
therefore the Sun and Earth do; but the Motion *1206
whereby theſe Bodies tend towards one another, is deduc'd from direct Obſervations; which ſoever of theſe Bodies moves about the other, deſcribes Area's by Lines drawn to the Center of it, proportional to the Times, which is evident from aſtronomical Obſervations; therefore the Body mov'd is retain'd in a Curve, by a Force which is directed towards the Center of the
other*. Now as Re-action is always equal to * 226
Action*, unleſs the Laws of Nature, which ob- * 126
tain conſtantly every where, be wholly overturn'd, theſe two Bodies tend towards one another with equal Motions, that is, with Celerities that are inverſly as their Maſſes*, which is * 65
alſo immediately deduc'd from the Law of Gravity*. *1235

The Quantity of Matter in the Earth is next to nothing, in compariſon to the Quantity of Matter in the Sun, as we ſhall ſhew in the following Chapter; wherefore the *Sun muſt move*

very

very ſlowly whilſt the Earth comes towards it very ſwiftly.

Whence it follows, that the Earth is carried round the Sun, leſt it ſhould fall upon the Sun by that very violent Motion whereby it is retained in its Orbit.

This Motion of the Earth is alſo deduc'd from the ſame Principles another way.

Two Bodies that are carried towards one another by any Force, will at laſt concur, or continually recede from one another, unleſs each of them be ſo mov'd as to have a centrifugal Force, equal to the Force whereby it is carried towards the other Body; but as the Bodies which gravitate towards one another, tend towards each
* 126 other with equal Forces *, or what is the ſame *,
* 65 with Celerities that are inverſly as the Quan-
* 1235 tities of Matter *, theſe Bodies cannot perſe-
1248 vere in their Motions about one another, unleſs
both of them be ſo mov'd as to have equal centrifugal Forces, which does not happen, unleſs they both revolve in equal times about their common Center of Gravity; that is, if this Propoſition be applied to the Sun and Earth, unleſs they both move about a Point, whoſe diſtance from the Center of the Sun is to its diſtance from the Center of the Earth, as the Quantity of Matter in the Earth is to the Quantity of Matter in the Sun, they cannot perſevere in their
* 234 Motions about one another *: This Point, or
235 Center of Gravity, muſt of conſequence be
very near to the Sun's Center. Now ſince which ſoever of theſe Bodies moves, it perſeveres in its Motion about the other, it follows that both of them are affected by the Motions above-mention'd, and that the Sun is moved

but

but a little, whilst the Earth describes a very great Orbit; whence it follows, that the Motion of the Earth cannot be denied by any one who reasons from the Laws of Motion, that are deduc'd from Phænomena.

Having prov'd *the annual Motion of the Earth*, 1249
and brought back the Earth among the Planets, there remains but little difficulty in relation to the Motion of it *about its Axis*, for no Body that believes the annual Motion doubts of this; a great many who allow of the Motion about the Axis, deny the annual Motion; therefore it will be enough to observe by the bye, that all the Planets, concerning which any Observation could be made in respect of this Motion, do move about their Axes; and that the Earth has such a Motion, *the uniform diurnal Motion in Bodies, at any Distances, does plainly enough shew*; to which we must add, that the Celerity of the fixed Stars going thro' one whole Revolution in less than 24 Hours, can hardly be more probable than it is conceivable.

This Motion also is disagreeable to the Nature
of all *the heavenly Bodies*; for *if they are carried* 1250
round, they must every Day, with an equable Motion, describe Circles that have the Earth for their Center; that is, they must, by Lines drawn to the Center of the Earth, sweep thro' Area's proportionable to the times, and be retain'd in their Orbits by Forces which are directed towards
the Center of the Earth *, and by which (by rea- * 226
son that Action and Re-action * are equal) *the* * 126
Earth must also be continually attracted towards those Bodies, so that it *must necessarily be agitated by a very violent Motion*; whence it appears that the diurnal Motion must not be referr'd to the heavenly Bodies, but to the Rotation of the Earth about its Axis.

1251 Thoſe who obſtinately affirm that the Earth is at reſt, object, that Bodies upon the Surface of the Earth muſt (on account of their centrifugal Force) recede from the Earth along a Tangent to
* 217 a Circle parallel to the Equator *: We anſwer; That the Bodies, in the Places where they are, are carried round with the ſame Motion as the Surface of the Earth; and therefore, that in reſpect of the Points of the Surface, they endeavour
* 223 to recede in Lines perpendicular to the Axis *; but alſo that Bodies by Gravity tend to the Cen-
*1226 ter of the Earth *; and therefore by a Motion compounded of both theſe the Body is continual-
* 190 ly moved, or endeavours to move *; but becauſe
198 the firſt Motion is extremely ſmall in reſpect of the other, a heavy Body is turn'd but very little out of its Direction towards the Center, and the Gravity is a little diminiſh'd, ſo much the more as the Place is more diſtant from the Pole; which agrees with Experience. We ſhall hereafter ſhew, when we come to ſpeak of the Figure of the Earth, that the above-mention'd Direction of heavy Bodies is every where directed perpendicularly to the Surface of the Earth. A Body which is thrown upwards is acted upon, not only by the Motion wherewith it is thrown up, but it is alſo carried by the Motion that is impreſs'd to the Perſon or Machine that impels the Body; that is, it is carried by the Motion which is common with the Surface of the Earth, and therefore the Body moves in the ſame Line (the Line being carried on with the Surface of the Earth) as it would do if the Earth was at reſt.

CHAP.

CHAP. XIV.

Concerning the Density of the Planets.

BEfore we proceed to the physical Explanation of the System, we must determine the Quantities of Matter in some Bodies, and their Diversities; which being known, the Effects of the Laws by which these Bodies are govern'd will more easily appear.

The Quantities of Matter in different Bodies are to one another as the Gravities at the same distance from these Bodies *, which Gravities are *1207
to one another inversly as the Squares of the periodical Times of the Bodies revolving about those different Bodies at the same distance *; by multi- * 236
plying the Quantities which are in this Ratio by the same Quantity (*viz.*) by the Cube of this distance, the Ratio of these Quantities will not be chang'd, which are therefore to one another as the Quotients of the Divisions of the above-mention'd Cube by the Squares of the periodical Times aforesaid; but the Quotient of such a Division is found for any Body by dividing the Cube of the other distance, let it be what it will, by the Square of the periodical Time of the Body revolving at that distance, for such Quotients are equal to one another for all Bodies that revolve about the same Body at any Distances, as follows from the Equality of the Ratio between the Cubes of the Distances and the Squares of the periodical Times at those Distances *; from which we de- * 974
duce, that *the Quantities of Matter in any Bodies in our System, are to one another directly as the Cubes of* 1252
the Distances at which other Bodies revolve about

these, and inversly as the Squares of the periodical Times of these revolving Bodies.

These things are demonstrated by setting aside the Agitation of the central Body, whose Quantity of Matter is enquired after.

By reason of the Sun's Magnitude in respect of *Venus*, *ex gr.* which alone we consider of the Planets, the Sun is scarce mov'd by the Action of
1235 that Planet; and *Venus* may be consider'd as moving about a quiescent Body.

The Satellites of *Jupiter* and *Saturn* are indeed carried by the common Motion along with the primary Planets, but by reason of the Magnitude of the primary Planets, they are carried about them as about Bodies that are at rest.

But the Moon acts sensibly enough upon the Earth, and moves it; wherefore before we can compute the Motion of the Moon by the help of
1252 the aforesaid Rule, in order to compare the Quantity of Matter in the Earth with the Quan-
1253 tities of Matter in the *Sun*, *Jupiter*, and *Saturn*, we must determine *the distance at which the Moon would move about the Earth*, if it was at rest (that is, *not carried about by the Action of the Moon) in the same periodical Time in which it now performs its Revolution*; here also we don't take notice of the Motion that is common to the Earth and Moon, by which they are both carried about the Sun.

The Moon perseveres in its Motion about the Earth, therefore the Earth and Moon are mov'd about a common Center of Gravity, as follows from what has been demonstrated concerning the
1248 Earth and the Sun; and the Moon (with that Force with which it tends towards the Earth) revolves in an Orbit, whose Semidiameter is the distance of the Moon from the aforesaid common Center of Gravity of the Moon and the Earth.

Let

Let L be this distance of the Moon from the common Center of Gravity, T the distance of the Earth from the same Center, $L + T$ therefore is the distance of the Moon from the Earth, and is 60 half Semidiameters of the Earth; for here we consider the mean distance. Let D be the distance which we would have, at which the Moon, by its Gravity towards the Earth, would move about the Earth, if it was at rest, in the same Time in which it is now mov'd about the common Center of Gravity at the distance L.

By reason of this Equality of the periodical Times, the Force whereby the Moon would be kept in its Orbit at the distance D, is to the Force whereby it is kept in its Orbit at the distance L, as D to L*. * 232

But the Force whereby the Moon would tend to the Earth, and be kept in its Orbit at the distance D, is to the Force whereby it is now kept in its Orbit at the distance $L + T$, as $\overline{L+T}^q$ to D^q*. Therefore, *1208

$$D, L :: \overline{L+T}^q, D^q$$

consequently $D^c = L \times \overline{L+T}^q$, and $D^c \times \overline{L+T} = L \times \overline{L+T}^c$: whence we deduce the following Proportion;

$$\overline{L+T}, D^c :: L+T, L.$$

Therefore $L + T, D :: L + T$, is to the first of two mean Proportionals between $L + T$ and L.

$L + T$ is to L, as the Quantity of the Matter in the Earth and Moon taken together, to the Quantities of Matter in the Earth alone*; which * 234
Quantities of Matter, as we shall shew hereafter, 235
are to one another as 40,37. to 39,37. and the first of two mean Proportionals to these Numbers

 is

is 40,035; therefore 40,37. is to 40,035. as $60\frac{1}{7}$ to the distance required, which is found to be 60 Semidiameters of the Earth.

Concerning this Operation, it is to be noted, that the distance D cannot be discover'd, unless the Ratio between the Mass of the Moon and the Earth be known; which cannot be determined, unless the Ratio between the Density of the Sun and the Earth be found; to discover which, it is necessary that the distance D be known; wherefore D is discover'd at first by Trials, and is exactly determin'd by Approximation; but it is certain that this is 60 Semidiameters of the Earth; because this being suppos'd, it is found that the Ratio between the Quantities of Matter of the Moon and the Earth is as 1 to 39,37. as we shall see hereafter; by making use of which Proportion, this distance is discover'd to be 60 Semidiameters, as we have shewn.

These things being premis'd, we proceed to the Computation.

The distance of *Venus* from the Center of the Sun is 723, and its periodical Time is 5393
* 959 Hours*.

The fourth Satellite of *Jupiter* is distant from the Center of *Jupiter* 12,507. such Parts of which *Venus* is distant from the Sun 723; the periodical
* 971 Time of this Satellite is 402 Hours, 5 Minutes*.

The fourth Satellite of *Saturn* is distant from the Center of *Saturn* 9,292. of the same Parts;
* 972 and its periodical Time is 382 Hours 41 Min.*

Lastly, the distance of the Moon is 60 Semidiameters of the Earth from its Center, and 2,909, of the aforesaid Parts; its mean periodical Time is 655 Hours, 43 Minutes.

If

If you divide the Cubes of these Distances respectively by the Squares of the periodical Times, you will have in the Quotients, Numbers which are to one another as the Quantities of Matter in the aforesaid central Bodies*; which Quotients are to one another as the following Numbers. 1254 *1252

	In the Sun.	*In Jupiter.*	*In Saturn.*	*In the Earth.*
Quantities of Matter	10000.	9,248.	4,223.	0,0044.

We have also the Proportion of the Diameters of these Bodies from astronomical Observations, as follows. 1256

	Of the Sun.	*Of Jupiter.*	*Of Saturn.*	*Of the Earth.*
Diameters	10000.	1077.	889.	104.

If the Quantities of Matter abovesaid be divided by the Squares of the Diameters, the Quotients will be to one another as the Weights on the Surfaces of the aforesaid Bodies*; and these Quotients are as the following Numbers. 1257 *1227

	Of the Sun.	*Of Jupiter.*	*Of Saturn.*	*Of the Earth.*
Gravities on the Surfaces	10000.	797,15.	534,337.	407.832.

1258

If you divide these Numbers by the Diameters, you will have the Proportion of the Densities of those Bodies*. 1259 *1231

The Quotients found by these Divisions are as the following Numbers.

	Of the Sun.	*Of Jupiter.*	*Of Saturn.*	*Of the Earth.*
Densities	10000.	7404.	6011.	39214.

1260

We ſhall determine the Denſity of the Moon in the laſt Chapter.

It is not probable that the aforeſaid Bodies are homogeneous; we ſhall ſhew in relation to the Earth, in the 17th Chapter, that it is denſer towards the Center than towards the Surface; from whence it follows, that the Denſities cannot be exactly determin'd; wherefore *we* only *determine the mean Denſities*, that is, *which the Bodies would*
1261 *have, if the ſame Bodies, keeping the ſame Quantity of Matter and Bulk which they now have, ſhould become homogeneous.*

1262 *The above-mention'd Proportion* between the Den-*
*1260 *ſities, in reſpect of all the Bodies, and the reſt of the Computations in reſpect of the* Sun, Jupiter, *and* Saturn, *are free from any ſenſible Error; when they are compared with the Earth there may be ſome Error*, which muſt be corrected by Obſervations to be made hereafter; for we ſuppoſe the diſtance of the Moon (which is 60 Semidiameters of the Earth) to be 2,909 ſuch Parts, of which *Venus* is diſtant from the Sun 723, that is, of which the
* 959 Earth is diſtant from the Sun 1000*; which di-
960 ſtance of the Moon is diſcover'd by ſuppoſing the horizontal Parallax of the Sun 10", which cannot be look'd upon as abſolutely true, altho' it be deduc'd from the moſt exact Obſervations that have hitherto been made of the Parallax of *Mars* when it is neareſt of all to the Earth, which is too ſmall
1108 to leave us without Suſpicion of ſome Miſtake.

But the Error, in not determining truly the Proportion between the Semidiameter of the Earth and the diſtance from the Sun, does not change the determin'd Denſity of the Earth, as is deduc'd from Computations made about it.

For it follows from theſe, that the Denſities of Bodies are to one another in a Ratio compounded of the direct Ratio of the Cubes of the Diſtan-

ces of the Bodies carried about, and the inverse Ratio of the Squares of the periodical Times of these revolving Bodies*; as also of the inverse *1254
Ratio of the Cubes of the Diameters of the central Bodies, whose Densities are required*; the Ra- *1257
tio, compounded of these, is compounded of the 1259
direct Ratio of a Fraction, whose Numerator is the Cube of the distance of the revolving Body, and whose Denominator is the Cube of the Diameter of the central Body, and the inverse Ratio of the Square of the periodical Time of the Body carried about; but you have such a Fraction, if you know the Ratio between the Diameter of the central Body and the distance of the revolving Body from that Center, altho' this distance can be compar'd with no other; but this Ratio is given in respect of the Earth and Moon, as well as in respect of the other Bodies; wherefore also the Ratio of the Density of the Earth to the Densities of the other Bodies is exactly discover'd.

CHAP. XV.

The physical Explanation of the whole planetary System.

IN the first Part of this Book we have shewn what are the Motions of the Bodies in the planetary System; now we must explain how *124
these Motions follow from the Laws of Nature*; 125
that is, how these Bodies, being once put in mo- 126
tion, persevere in those Motions which we ob- 1206
serve. 1207

Let us conceive the *Sun* and *Mercury* to be left 1208 1263
to themselves, and they will come together*; but *1206
if they be projected, they may revolve about a common

common Center of Gravity in equal Times, and
1248 describe immoveable elliptic Lines, and perse-
1208 vere in that Motion; for it is plain, by mathe-
241 matical Demonstration in that Case, that the Bodies will describe Ellipses about the common Center of Gravity, similar to that which the one of them could describe with the same Forces about the other, if it was at rest; this Center, on ac-
* 235 count of the Sun's Magnitude*, is very little distant from the Center of the Sun itself.

Let us conceive besides, *Venus* to be projected at a greater distance from the Sun, it will a little disturb the Motion of *Mercury*, which also, by its Action upon *Venus*, will turn it a little out of the way, and both will draw the Sun, sometimes the same way, and sometimes different ways; but we find all these Irregularities are insensible, if we consider the Magnitude of the Sun, and therefore that these three Bodies tend towards a Point that is between them near the Sun, which therefore is very little distant from the common Center of Gravity of them all.

If the Earth, *Mars*, and the other Planets be successively projected at different Distances from
1264 the Sun, the same Reasoning will hold good; whence it follows, that *all the Planets are revolved about the common Center of Gravity of all the Bodies which compose the System*, which is but little distant from the Sun, and that the Planets do not sensi-
1265 bly disturb one another in their Motions; wherefore *they all describe the same Line singly, which they would describe about the Sun, if every one of them was alone with the Sun in the planetary System*, that is, immoveable Ellipses; for it is plain that these
1208 will be describ'd by the Force of Gravity; and
241 it is prov'd by mathematical Demonstration, that no other immoveable eccentric Lines can be describ'd by a central Force acting equally at equal Distances.

It

It will also more plainly appear, that all the Planets tend to a Point near the Sun, if we consider that the Quantity of Matter in the Sun is 1000 times and more greater than the Quantity of Matter in *Jupiter*, which is far the greatest of all the Planets*. *1255

When all *the Planets move*, tho' they move *the* 1266 *Sun* but little, yet they do move it, and draw it differently, according to their different Situation in respect of one another; whence there arises a small Motion in the Sun, which always depends upon the Motion already acquired, and the Change which happens in it from the Action above-mention'd, which varies every Moment.

It is owing to this Agitation of the Sun, that the 1267 *Planets disturb one another less in their elliptic Motions round the Sun, than if the Sun was at rest in the middle of the System.* If *Jupiter*, *ex gr.* was equally distant from *Mercury* and the *Sun*, it would attract both those Bodies to itself with an equal Celerity*; whence the Situation, in respect *1235 of the Sun, is less chang'd than if the Sun was not agitated by this Motion, and *Mercury* only was attracted by *Jupiter*. According to the various Distances of *Mercury* and the *Sun* from *Jupiter*, the one or the other is more attracted, and there is always a less Change in their respective Situation when both are carried the same way, than if (the Sun being at rest) *Mercury* only should be carried towards *Jupiter*.

This Reasoning may be applied to all the Actions of the Planets that are more distant from the Sun upon those that are less distant. As to what relates to the Action of those that are nearer upon those that are farther from the Sun, according to the different Situation they draw a Planet to the Sun, or drive it from the Sun, and in considering one whole respective Revolution, that is, the

the Motion from one Conjunction to another, the Disturbance is less than if the Sun was immoveable.

1268 The Magnitude of the Sun, compar'd with the rest of the Bodies of our System, is the reason (as appears by what has been already demonstrated) that the Planets disturb one another but little; but since the Magnitude is not infinite, these mutual Actions must not be wholly overlook'd.

We have said, that it appears by astronomical Observations, that *Jupiter* alters the Way of *Sa-*
*1217 *turn* when it is nearest to it*; why this Disturbance is more sensible than the rest, is deduc'd from the Law of Gravity.

1269 The Actions of *Jupiter* upon *Saturn* when it is nearest to it, and of the Sun upon the same Planet, by which it is kept in its Orbit, are to one another directly as the Quantities of Matter in
*1207 *Jupiter* and the Sun* (*viz.*) as 9,248. to 10000*,
*1255 and inversly as the Squares of the Distances of *Jupiter* and the Sun from *Saturn*, that is, directly as 81 to 16; for the Distances of *Saturn* and *Jupiter* from the Sun are almost as 9 to 5; where-
1270 fore when *Jupiter* is nearest to *Saturn*, the Distances of *Saturn* from *Jupiter* and the Sun are as 4 to 9. The Ratio compounded of the two aforesaid Ratio's is as 749 to 160000, or as 1 to 214. This *Action of* Jupiter *conspires with the Gravity of* Saturn *towards the Sun, and* therefore *increases* $\frac{1}{214}$ Part; whence it is no Wonder that the Disturbance is sensible.

We don't here consider the Force by which *Jupiter* attracts the Sun, for the Orbit of *Saturn* is not chang'd by it; and what we had to explain was, why Astronomers observe *Saturn* to be turned out of the way; yet by the Action of *Jupiter* upon the Sun, the Sun is brought nigher to *Saturn*,

turn, and the respective Situation of these Bodies is more disturb'd than is discover'd by astronomical Observations; the Force with which *Jupiter* in the aforesaid Position attracts the Sun, and with which therefore the Sun is attracted towards *Saturn*, is to the Force with which *Jupiter* attracts *Saturn* as 16 to 25*; that is, as 479 to 749; *1208
which Number expresses the Force with which *Saturn* tends towards *Jupiter*, when the Gravity of *Saturn* towards the Sun is express'd by 160000. If we collect into one Sum the Forces of *Jupiter*, by which it attracts *Saturn* and the Sun, the Force by which, from the Interposition of *Jupiter*, these Bodies tend towards each other, will be to the Gravity of *Saturn* towards the Sun as 1228 to 160000; but this Gravity is to the Gravity of the Sun towards *Saturn* as 160000 to 67,5*; *1207
wherefore *the mutual Access or Approach of the* Sun 1255
and Saturn, *is to the Increase of this Approach by the* 1271
Action of Jupiter *interposed*, as 160067 to 1228, or as 130 to 1.

This Disturbance is remarkable, and far the greatest of any that happens in the Motion of any of the primary Planets; this also obtains only in this one Case of the Conjunction; for when *Jupiter* recedes from *Saturn*, the Disturbance of the Motion of *Saturn* in a short time becomes insensible.

In the same Position of *Jupiter*, when it is nearest to *Saturn*, the Force of *Saturn*, altho' it be the greatest of all in this Case, does not so sensibly alter the Way of *Jupiter* about the Sun; the Action of *Saturn* attracting *Jupiter*, is to its Action by which it attracts the Sun, as 81 to 16*; there- *1208
fore it attracts *Jupiter* with greater Celerity; and since they are both attracted the same way, the difference of these Forces is the Force with which

(from

(from the Action of *Saturn*) *Jupiter* and the Sun
* 175 are separated from each other*, which is therefore to the Gravity of the Sun towards *Saturn* as
65 to 16; but this Gravity of the Sun towards
Saturn is to the Gravity of *Jupiter* towards the
1207 Sun as 4,223. to 10000, and as 25 to 81*;
1255 that is, as 106 to 810000, or as 16 to 122756;
*1208 therefore the disturbing Force of *Saturn* is to
the Gravity of *Jupiter* towards the Sun as 65 to
1272 122756, or as 1 to 1888; therefore *by the greatest Action of* Saturn, *the Gravity of* Jupiter *towards the Sun is diminish'd only by* $\frac{1}{1888}$ *Part*, which Disturbance is insensible.

The other mutual Disturbances of the Planets are much less, as will appear by determining that, which is the greatest of them all (*viz.*) that of *Mars* by *Jupiter*, which is discover'd by the same sort of Computation as the foregoing.

The distance of *Jupiter* from *Mars* and the Sun, when *Mars* is between the Sun and *Jupiter* in the
* 961 same Line, are as 7 to 10*; wherefore the For-
962 ces with which *Jupiter* attracts these Bodies, are
1280 as 100 to 49; the difference of which Forces is
to the Gravity of the Sun towards *Jupiter* as 51
to 49. This Gravity of the Sun towards *Jupiter*,
is to the Gravity of *Mars* towards the Sun, as
1207 9,248 to 1000, and as 9 to 100*; that is, as
1255 83 to 1000000, or as 49 to 590443; and the di-
*1208 sturbing Force of *Jupiter*, is to the Gravity of
Mars towards the Sun, as 51 to 590443, or as 1
1273 to 11577; wherefore *the Gravity of* Mars *towards the Sun is diminish'd only* $\frac{1}{11577}$ *Part by the Action of* Jupiter *when nearest to it*.

Altho'

Altho' these Disturbances, arising *from the Actions of the Planets upon each other*, be very small, 1274
and altho' those which happen in a different Position of the Planets, do in some measure compensate each other, yet the Proportion in which the Force which keeps the Planets in their Orbits decreases, is a little chang'd by these Actions, so that it does not decrease exactly in an inverse Ratio of the Square of the Distance; therefore altho' the Orbits are at rest as to Sense, *after a great many Revolutions, a small Change is observ'd in their Situation**. * 243

From all this it follows, that if we suppose the 929
Planets at first once projected at the Distances 1275
from the Sun, at which they are mov'd, they will, by the Laws already explain'd, persevere in those Motions; and the Eccentricity of the Orbits depends upon the Celerity and Direction of the first Projection; but these Motions may be preserv'd very long by reason of the small Resistance of the celestial Matter.

It is also plain, why, by Lines drawn to the Center of the Sun, they describe Area's proportionable to the Times; namely, because all other Gravities in the System are very small in respect to the Gravity towards the Sun*; therefore by * 1265
this Gravity alone it is that they are retain'd in their Orbits; whence follows this Proportion of the Area's*. And also the Motion in elliptic * 225
Lines, which are carried on very slowly, follows from the Law of Gravity; and these Lines would also be immoveable, if the Planets gravitated only towards the Sun*; but this slow * 241
Motion of the Orbits is deduc'd from the Action 1208
of the Planets upon one another*. Now in re- * 1214
spect to the Proportion which is observ'd between the Cubes of the Distances and the Squares of the periodical Times, it is also deduc'd from the

* 239 the Law of Gravity *; so that if we add to these
1208 what we have said of the Deflection of *Saturn**,
*1217 1270 nothing will remain to be explain'd in respect to
the primary Planets.

1276 That *the Motion of Comets depends upon the Law
of Gravity, is also deduc'd from Observations;
and in respect of them, as has been said concerning
the Planets, the Sun's Gravity prevails, and
by that Gravity they deflect from a rectilinear
* 980 Course *; but that the Curvature of their Way
226 depends upon the same Gravity, follows from
this; that a Body, by that Gravity, will describe
an Ellipse, or a Parabola, or an Hyperbola
* 241 bola *; which Lines it appears that those Comets
1208 have described, whose Trajectories have been determined.

1277 *The Satellites of* Jupiter *and* Saturn *are moved*
* 944 *by the same Laws about their Primaries, as the Pri-*
966 *maries are moved about the Sun**; wherefore the
974 *1275 Explication of those Motions * may be also referr'd
to them; for in these three Cases, smaller
Bodies are revolving at different Distances about
a much greater Body; namely, Satellites about
Jupiter and *Saturn*, and primary Planets about
the Sun.

1278 *Whilst secondary Planets are moved about a primary
one, it is evident that they may all be moved
with one common Motion*, whereby the respective
Motions with which they are mov'd in respect of
each other, will not be disturb'd, because a Body
may at the same time be mov'd by different Im-
* 125 pressions *; the Motion that a primary Planet
has in common with its Satellites, is the Motion
of a primary Planet about the Sun.

1279 Yet *the Motion of the secondary Planets is disturb'd
by the Action of the Sun*, towards which they are carried,
sometimes faster, sometimes slower, according
to the different Position of the Primary; and
they

they alſo often concur towards the Sun's Center in different Directions. Theſe Irregularities, which are very ſmall, cannot be obſerv'd in the Satellites of *Jupiter* and *Saturn*, tho' they be really like thoſe which are obſerv'd in the Motion of the Moon; the leaſt Deviation of this laſt is very ſenſible to us. But that the Irregularities of the Moon exactly follow from the Theory of Gravity, will appear in the next Chapter.

CHAP. XVI.

The phyſical Explication of the Moon's Motion.

IT is certain that the Moon and Earth having 1280
once a projectile Motion given them, they can perceive in their Motion about their common Center of Gravity*, if they be carried any way *1263
by a common Impreſſion directed in parallel Lines, as was ſaid of the Satellites of *Jupiter* and *Saturn**, this Motion will not diſturb the Motion *1278
about the common Center of Gravity, which will follow that Direction only, becauſe in reſpect of the two Bodies it is at reſt; but the Bodies are carried by a Motion compounded of that Impreſſion, and of the Motion about the common Center of Gravity*, that is, they are whirl'd about * 190
that Center as it is carried along, as before its Motion when it was at reſt. If every Moment new Impreſſions common to both the Bodies act upon them, the Way of the Center of Gravity may be chang'd every Moment; which Change will be like that which the Bodies themſelves would undergo if they had no reſpective Motion.

Hence we deduce, that if whilſt the Moon and Earth are whirl'd round their common Center of Gravity they be both projected, the Way of the Center of Gravity, by the Action of the Sun acting upon both Bodies, is the ſame as a Body projected in the ſame manner would deſcribe about the Sun.

1281 Whence it follows, *that the Moon diſturbs the Motion of the Earth, and that the common Center of Gravity of thoſe Bodies deſcribes that Orbit about the Sun, which we have hitherto ſaid that the Earth deſcrib'd*; becauſe we look'd on the Action of the
1282 Moon; but *the Earth deſcribes an irregular Curve.*

1283 *Fig.* 4. *Plate* XXIV.] Let the Sun be at S, and the common Center of Gravity of the Moon Q, and the Earth at M, at the time of the Full-moon, be at F; after one whole Lunation, that is, the next Full-moon, let that Center be at A; and let F D A be the Orbit which we call that of the Earth, but in which it is the Center of Gravity above-mention'd that does really move.

If this Lunation be divided into four equal Parts, after the firſt, the Center of Gravity will be at E, the Moon at P, and the Earth at L; after the ſecond, Part of the Time at New-moon the Center of Gravity will be at D, the Moon at R, and the Earth at I; in the following Quadrature the Center of Gravity will be at B, the Moon at O, and the Earth at H. Laſtly, at Full-moon the Center of Gravity being at A, the Moon will be at N, the Earth at G; all which follows from the Revolution of the Earth and Moon about their common Center of Gravity, whilſt it is carried in the Orbit about the Sun.

Therefore we ſee the Earth moves in the Curve M L I H G, which is twice inflected in each Lunation; which Curve alſo does not return into itſelf,

ſelf, becauſe the Inflections in the ſeveral Revolutions about the Sun do not coincide; for 12 Lunations, and a third Part of another, are perform'd every Year.

This Irregularity of the Motion of the Earth, which is deduc'd from the Laws of Nature, *is too ſmall to become ſenſible in aſtronomical Obſervations*; wherefore we may without any Error ſay, that the Center of the Earth itſelf deſcribes the Orbit FDA; for MF, or DI, the greateſt diſtance of the Earth from that Orbit, is about the 40th Part of the diſtance IR, which diſtance itſelf is not the 300th Part of the diſtance FS. 1284

In explaining what relates to the Moon, we alſo neglect the Conſideration of the Motion of the Earth about the common Center of Gravity above-mention'd, but we ſuppoſe it to revolve at the diſtance of 60 *Semidiameters from the Center of the Earth*; becauſe, as we have before demonſtrated *, ſuch is the diſtance at which in its periodical Time it could revolve about the Earth at reſt, or be carried along in an Orbit in which it ſhould not be diſturb'd by the Moon's Action; by this Method the Moon's Irregularities will be much more eaſily diſcover'd, for they are the ſame, as is evident, whether the Moon moves about the common Center of Gravity of the Moon and Earth, or about the Center of the Earth itſelf. 1285 *1253

Plate XXV. *Fig.* 1.] Let S be the Sun, T the Earth, and the Orbit of the Moon ALB*l*; and laſt of all, let the Moon be at A in the Quadrature; it tends towards the Sun in the Direction AS, in the ſame manner and with the ſame force that the Earth is carried towards S along TS, becauſe the Diſtances AS and TS are equal; this Force may be repreſented by TS or AS, whereby the Moon endeavours to deſcend along AS, 1286

and is resolv'd into two Forces, by drawing the Parallelogram ADST; so that the Moon will endeavour to move in the Directions AD and
* 192 AT by Forces represented by those Lines*.

By the Force which acts along AD, the Moon is carried with the same Celerity and the same Way of the Earth, by reason of the equal and parallel Lines TS and AD; wherefore by this Motion the relation between the Moon and Earth is not chang'd, but the Force along AT con-
1287 spires with *the Gravity of the Moon towards the Earth*; and this Gravity *is increased by the Action of the Sun when the Moon is in the Quadratures; and the Augmentation or Addition is to the Gravity of the Earth towards the Sun, as* AT, *the Moon's distance from the Earth, is to* TS, *the Earth's distance from the Sun.*

1288 TS, *the Earth's distance from the Sun, remaining the same, the* above-mention'd *Addition of Gravity increases, and diminishes in the Ratio of the Line* AT, *the distance of the Moon from the Earth.*

But this distance of the Moon from the Earth AT, if it remains the same, and TS be increased, then AT will be less in respect of AS; therefore tho' there should be no Change in the Force, whereby the Earth and Moon fall towards the Sun, the Addition will be less, and so much less as TS is greater, that is, it will be inversly as TS; but the Force of Gravity does not remain the same when TS is increas'd, but is diminish'd; wherefore also in that respect the above-mention'd Addition is diminish'd, and in the same Ratio with that Force of Gravity, therefore it is the in-
1208 verse Ratio of the Square of the distance TS; if this Diminution be added to that above-mention'd, we see that the Addition of which we speak,

ſpeak, *follows the inverſe Ratio of the Cube of the* 1289
diſtance of the Earth from the Sun.

The diſtance of the Earth from the Sun remaining 1290
the ſame, the Gravity of the Moon towards the Earth decreaſes more ſlowly in the Quadratures, than according to the inverſe Ratio of the Square of the diſtance from the Center of the Earth; for if the Addition in that Caſe ſhould follow the inverſe Ratio of the Square of the diſtance, as the Gravity from the Action of the Earth does*, this Ratio would *1208
not be diſturb'd; but the Addition increaſes when the Gravity itſelf is diminiſh'd; wherefore the Addition, when the diſtance is increas'd, is always greater than is required, and conſequently the Diminution the leſs.

This Addition is determin'd *in the mean Di-* 1291
ſtances of the Moon from the Earth, and of the Earth from the Sun. Let A T and T S be theſe mean Diſtances, the *Addition* required is to the Gravity of the Earth towards the Sun as A T to T S*; *1287
the Gravity of the Earth towards the Sun, *is to the Gravity of the Moon towards the Earth* (becauſe theſe Bodies are retain'd by theſe Gravities in their Orbits) directly as T S to T A, and *inverſly as the Squares of the periodical Times of the Earth about the Sun, and of the Moon about the Earth**; * 237
therefore the Addition required is to the Gravity 1236
of the Moon towards the Earth, in a Ratio compounded of theſe Ratio's; that is, the abovemention'd inverſe Ratio of the periodical Times of the Earth and Moon, the other Ratio's deſtroying one another; theſe Times are given, and their Squares are inverſly as 1 to 178,73.

Now if the Moon be at L. [*Plate* XXV. *Fig.* 1.] 1292
in which Situation the Sun attracts the Moon and Earth in the ſame Line, but not equally, the Moon it draws with a greater force, becauſe it is leſs diſtant from it; the difference of thoſe Forces

 is

is the Force by which the Moon is drawn back from the Earth, and by which the Gravity of the Moon towards the Earth is diminiſh'd.

The Forces whereby the Moon at L, and the Earth at T, tend towards the Sun, are to one
1208 another as the Squares of the Lines S T and S L; and the difference of the Forces, that is, the diſturbing Force, is to the Force by which the Earth deſcends toward the Sun, as the difference of thoſe Squares to the Square of the Line L S, that is, nearly as double L T to L S or T S, for theſe Lines do but very little differ from one ano-
1293 ther; and *the difference of the Squares, whoſe Roots differ but little, is keeping the Proportion double that which is between the Roots.*

If therefore T S, as before, repreſents the Force whereby the Earth deſcends towards the Sun, L l will repreſent the diſturbing Force and diminiſhing Gravity, when A T repreſents the diſturbing
1286 Force in the Quadratures. Let the Moon be at
1294 l, it is again (together with the Earth) attracted by the Sun in the ſame Line; but the Earth, becauſe leſs diſtant, moves more ſwiftly towards
1208 the Sun; ſo that there is a Force which ſeparates the Earth from the Moon, namely, the difference of the Forces which attract the Moon and the Earth; which Force always acts contrary to the Gravity of the Moon towards the Earth, and diminiſhes it, in the ſame manner as has been demonſtrated from the greater Gravity of the Moon towards the Sun, ſuppoſing it at L. At l alſo the ſeparating Force ſcarce differs from the ſeparating Force at L; for this Force, as we have ſhewn, is proportional to the difference of the Squares of the Lines T S and L S; and that (as appears by ſuch another Demonſtration) proportional to the difference of the Squares of the Lines l S and T S; which difference, by reaſon that L l

is very small in respect of T S, scarce differ among themselves; so that the Force which diminishes the Moon's Gravity at *l*, is also represented by L *l*.

Yet *the disturbing Force is something greater at the Conjunction* L *than at the Opposition* *l*; for suppo- 1295
sing the Differences between the Roots to be equal, the Squares, keeping the Proportion, will differ so much the more the less they are; and so keeping the Proportion, the Forces differ more at L and T than at T and *l*, which also are less*. *1208

From this we conclude, that *the Force which* 1296
diminishes the Gravity of the Moon in the Syzygies, is double that which increases it in the Quadratures; namely, as L *l* *to* A T; wherefore in the Syzygies the Gravity of the Moon from the Action of the Sun is diminish'd by a Part, which is to the whole Gravity as 1 to 89,36; for in the Quadratures the Addition of Gravity is to the Gravity as 1 to 178,73*. *1291

In the Syzygies the disturbing Force follows the 1297
same Proportion with half added to it, that is, with the disturbing Force in the Quadratures*; *1296
it is therefore *directly as the distance of the Moon from the Earth**, *and inversly as the Cube of the di-* *1288
*stance of the Earth from the Sun**. *1289

At the Syzygies the Gravity of the Moon towards 1298
the Earth receding from its Center, is more diminish'd than according to the inverse Ratio of the Square of the distance from that Center; for it would be diminish'd in that Ratio, if the Force to be taken away follow'd the same Ratio; but on the contrary, as it increases when the distance becomes greater*, the Diminution is always greater than *1297
in that Ratio.

1299 *Plate* XXV. *Fig.* 1.] Laſtly, let the Moon be at F, in any intermediate Place between the Syzygy and Quadrature, it is drawn towards the Sun along F S, by which, ſince it is leſs diſtant than the Earth T, it is attracted with more Force than the Earth; let the Force with which the Moon tends to the Sun be to the Force with which the Earth is carried towards it as F M to T S, which alſo before has been made uſe of to expreſs the ſame Gravity of the Earth; draw the Parallelogram F H M I, whoſe Diagonal is F M, and whoſe Side F H is parallel and equal to the Line T S; the Motion of the Moon towards the Sun is reſolv'd into two Motions, one along F H, the other along F I, and theſe Lines denote the Forces whereby the Moon endeavours to move
* 192 along them*; the Motion along F H is common to the Moon and the Earth, which with an equal Force, and in a Line parallel to it, does alſo tend to the Sun; ſo that by this Motion of the Moon, the Situation of it, in reſpect of the Earth, will not be chang'd, and the diſturbing Force will be only the Motion along F I.

By reaſon of the immenſe diſtance of the Sun, the Part M S of the Line M F is ſmall in reſpect of the whole, and the Angle F S T, where it is the greateſt, as A S T, is hardly more than the ſixth Part of a Degree; whence it follows, that the Lines M I and S N are very near one another, and that the Points I and N are ſcarce ſenſibly diſtant, and may, without any ſenſible Error, be confounded together; which Error, notwithſtanding how little ſoever it need be regarded in conſideration of one whole Revolution, is compenſated by a contrary Error when the Moon is at E; therefore the diſturbing Force is expreſs'd by F N.

It

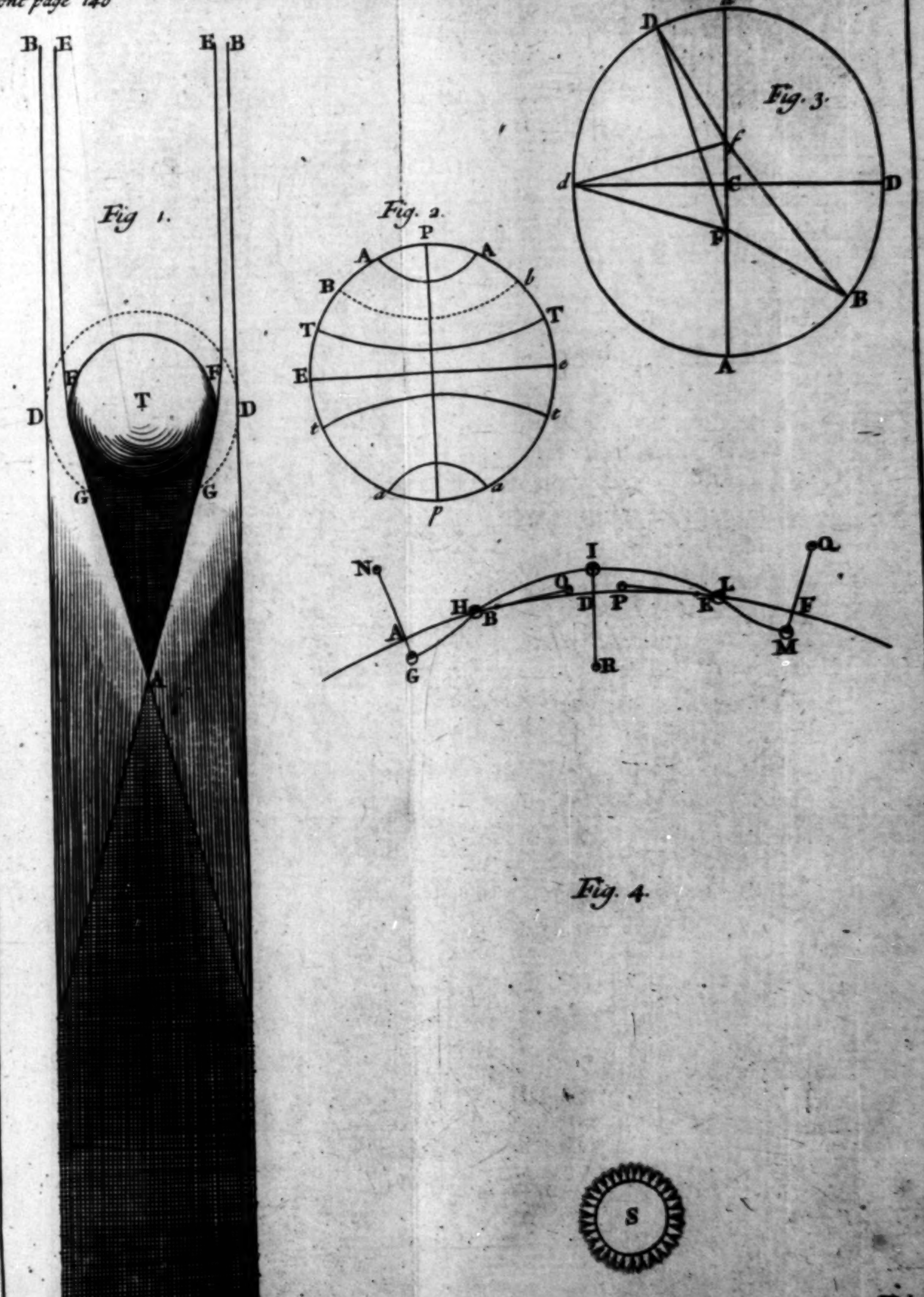
Fig 1.
B E E B
F F
T
D D
G G
A
Fig. 2.
P A A B b T T E e t t a a p
Fig. 3.
a D f d C D F B A
Fig. 4.
N I O Q H B D P L E F A G M R S

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It is to be obſerv'd, when only the Part E F of 1300
the Line E S is conſider'd, that it is to be look'd upon as parallel to the Line L *l*, becauſe of the ſmall Angle which theſe Lines make; from the Point N draw N Q perpendicular to the Line 1301
F T, continu'd if need be, in which the Moon gravitates towards the Earth, and let the rectangular Parallelogram E P N Q be drawn; let us conceive the Force along F N reſolv'd into two others, acting in the Directions F Q and F P, and repreſented by theſe Lines*; by the Force along * 192
F Q the Force of Gravity is diminiſh'd in the Caſe repreſented by this Figure, but it is increaſed when the Point Q falls between F and T; but by the Force along F P the Moon in its Orbit is drawn towards the next Syzygy L, and the Motion of the Moon is accelerated or retarded, according as this Force conſpires with, or acts contrary to the Moon's Motion.

Near a Syzygy the Gravity of the Moon is diminiſh'd, and the Line F Q, which follows the Proportion of this Diminution, grows leſs, receding from the Syzygy, till it vaniſhes at the diſtance of about 54 Deg. 44 Min. from it; at a greater diſtance of the Moon from the Syzygy Q falls in between F and T, and the Gravity of the Moon towards the Earth is increas'd by the Sun's Action; the Force along F P vaniſhes in the Syzygy L; receding from it, it increaſes quite to the Octant, which is the middle Point between the Syzygy and the Quadrature; and then it diminiſhes again, till it vaniſhes quite at B.

Between B and *l*, or *l* and A, the diſturbing 1302
Motions are determin'd in the ſame manner as in A L B, the oppoſite inferior Part of the Orbit; at E and F the Diminution of Gravity is equal, and in that Poſition it is drawn in the Orbit with an

an equal Force towards the Syzygy *l*, with that with which at F it is impell'd towards the Syzygy L.

1303 Hence it follows, *that in the Motion of the Moon from the Syzygy to the Quadrature*, between L and B, as alſo between *l* and A, *the Gravity of the Moon towards the Earth is continually increas'd, and the*
1304 *Moon is continually retarded in its Motion*; but *in the Motion from the Quadrature to the Syzygy*, between B and *l*, as alſo between A and L, *every Moment the Moon's Gravity is diminiſh'd, and its Motion in its Orbit is accelerated.*

You may determine the Forces upon which theſe Effects depend, by comparing them with the known Force whereby Gravity is increas'd in the
1291 Quadratures, and which is repreſented by the Moon's diſtance from the Center of the Earth.

1305 The Lines M I, H F, S T, are equal by Conſtruction; therefore when the Points I and N are confounded, M N is equal to S T, and M S is equal to N T; the Lines M F and S T repreſent the Forces whereby the Moon at F and the Earth at T are carried towards the Sun S, therefore they are as the Square of the Line T S to the
1208 Square of the Line F S; wherefore as F G is the difference of thoſe Lines, F M and T S differ
1293 from one another double the Line G F, and adding G F to the Line F M, the difference between G M and T S, that is, M S will be triple the Line F G; and therefore this is alſo the Quantity of the Line N T; now as F E is double
1300 F G, therefore N T will be to F E as Three to Two.

Let F T be continu'd, if need be, and from E draw E V perpendicular to it, the Triangles E V F and N Q T, which are rectangular, will be ſimilar, by reaſon of the alternate Angles
1300 V F E and Q T N; therefore N T is to F E, that

that is, 3 is to 2 as N Q, equal to F P, is to E V, which therefore is proportional to 2 third Parts of the Force which is expreſs'd by F P; but E V is the Sine of the Angle E T V at the Center, which is double the Angle E F V at the Circumference, equal to the Angle F T L, which is the diſtance of the Moon from the Syzygy; therefore *as the Radius* T A or T E *is to a Sine* 1306
and an half of double the diſtance of the Moon from the Syzygy, namely, F P, *ſo the Addition of Gravity in the Quadratures* (which is expreſs'd by the Radius T A) *is to the Force which accelerates or retards the Moon in its Orbit.*

The Computation of this Diminution of Gravity, and of its Increaſe at a leſs diſtance from the Quadratures, is deduc'd from the ſame Principles.

This Diminution is repreſented by the Line F Q, which is equal to Q T, *minus* the Radius; but from the Conſideration of the Triangles above-mention'd, V F taken once and an half is equal to Q T; therefore V T and an half, with half the Radius added to it, expreſſes the requir'd Diminution of Gravity; and *the Radius is to the* 1307
Sum or Difference of once and a half the Co-ſine of double the diſtance of the Moon from the Syzygy and half the Radius; as the Addition of Gravity in the Quadratures, to the Diminution or Increaſe of Gravity in that Situation of the Moon, concerning which the Computation is made.

We make uſe of the difference of the Co-ſine from half the Radius, when the Angle, whoſe the Co-ſine is, is greater than a right Angle, becauſe in that Caſe we make uſe of the Co-ſine of the Complement of the Angle to two right Angles; when in this ſame Caſe the Co-ſine and a half, which we make uſe of, is greater than half the Radius,

Radius, the Quantity found is to be added; that is, increases the Gravity, which obtains every where between the Quadrature, and 35 Deg. 16 Min. from it.

1308 *These Forces, whatever is the Figure of the Moon's Orbit, are exactly determin'd*; for they are compared with the Addition of Gravity in the Quadratures, supposing the Moon in the Quadrature to be at the same distance from the Earth, at which it really is in the Place which is consider'd;
1291 but this Addition is discover'd in every Case.

1288 Tho' it be foreign to the Purpose of this Work
1289 to give a Computation of the Moon's Motion, I thought it necessary to explain in a few Words what is the Method whereby to discover the Forces that govern the Moon; because the more exactly we know the Forces, the more easily we shall conceive their general Effect.

Now to examine the Moon's Motion, we must singly consider its several Irregularities; which to do without Confusion, we must remove several Irregularities, and conceive the Moon as moving in a Circle about the Earth, in which Curve it is
* 241 plain that it can be retain'd by Gravity*; this
1208 Motion is disturb'd by the Action of the Sun,
1309 *and the Orbit is more convex in the Quadratures than in the Syzygies.* The Convexity of a Curve, which a Body describes by a central Force, is so much the greater, as the central Force does more strongly every Moment turn the Body out of the way; it is also the greater the more slowly the Body moves, because the central Force acting the longer, has a greater Effect in inflecting the way of the Body. From contrary Causes the Convexity of the Curve is diminish'd; both concur in increa-
*1303 sing the Convexity of the Orbit in the Quadra-
1304 tures, and diminishing it in the Syzygies*.

From

From this it follows, that the circular Figure 1310
of the Moon's Orbit is chang'd into an Oval, whose greater Axis goes thro' the Quadratures, so that the more convex Parts are in the Quadratures; wherefore *the Moon is less distant from the Earth at the Syzygies, and more at the Quadratures*; and it is no Wonder that the Moon comes towards the Earth when its Gravity is diminish'd, because the Access is not the immediate Effect of this Diminution, but of the Inflexion of the Orbit towards the Quadratures.

The Motion of the Moon, taking away the Action of the Sun, is not in a Circle, but in an Ellipse, one of whose Foci coincides with the Center of the Earth*; for the Orbit of the Moon * 967
is eccentric, and it is retain'd in it by the Force 241
of Gravity. 1280

Therefore what has been demonstrated cannot be exactly applied to the Moon's Motion; for as the Forces, which generate the Deviations explain'd, do really act upon the Moon, the Ellipse, which the Moon would describe if the Sun was taken away, is chang'd, *and* cæteris paribus, 1311
the Propositions of N° 1309, 1310, *may be applied to the Moon's Motion.*

In the Quadratures and Syzygies the disturbing 1312
Force acts in the same Line as the Force of Gravity towards the Earth*; therefore the Force *1286
which continually acts upon the Moon, and re- 1292
tains it in its Orbit, is directed towards the Cen- 1294
ter of the Earth; and *the Moon describes Area's, by Lines drawn to the Center of the Earth, proportional to the Times*. * 215

Plate XXV. *Fig.* 1.] *In other Points of the Orbit*, 1313
as F, besides the Force which acts in the Line F T, there is also another, whose Direction is perpen-

1301 perpendicular to F T, which is here represented
by F P; the Direction of the Force compound-
ed of both, is directed sometimes sidewise to the
Line F T, and does not tend to the Center of
* 190 the Earth*; wherefore *the Area's, by Lines drawn
to the Center of the Earth, are not exactly proportio-*
* 226 *nal to the Times**. In the Octants F P is the great-
est of all; and the Force, which is represented
by that Line, is to the Gravity of the Moon to-
wards the Earth, in that Point, in the mean Di-
1306 stances of the Sun and Moon, as 1 to 119,49;
1307 wherefore the Direction of the Force, compound-
ed of the Actions of the Sun and Earth upon the
Moon, makes an Angle of above half a Degree
with the Line F T.

The Motion of the Moon is subject to several
other Irregularities, so that it describes a Curve
wholly irregular; which Astronomers, in order
to subject it to the most exact Computations that
can be made, do *reduce to an Ellipse, which they*
1314 *conceive to be agitated by various Motions, and also to
be changeable, lest the Moon should go out of it.*

In respect to central Forces, we have observ'd,
that a Body does not describe an Ellipse, if the
central Force, by which it is retain'd in its Orbit,
decreases in any other Ratio than the inverse Ra-
tio of the Square of the distance, but that the
Curve may be often reduc'd to a moveable El-
* 243 lipse*; concerning which it is to be observ'd,
1315 that *the Ellipse* in that Motion *turns about one of its
Foci, and the Motion of the Ellipse is directed the same*
1316 *way as the Motion of the Body in it, when the central
Force decreases faster than in the inverse Ratio of the
Square of the distance*; but *if the central Force de-
creases slower as you recede from the Center, the El-
lipse is carried the contrary way*; as these things
may be demonstrated mathematically.

Hence

Hence it follows, the Orbit of the Moon cannot be referr'd to an elliptic Orbit, unless you suppose it agitated by four Motions every Revolution; that is, unless the Line of the *Apsides*, which goes thro' the Center of the Earth, goes forwards twice, and backwards twice.

The Apsides of the Moon go forward when the 1317
*Moon is in the Syzygies**, or rather whilst the Moon *1315
moves between the Points, which are 54 Deg. 1298
44 Min. distant from them*. *In the Quadratures*, *1307
and between the Points, distant from them 35
Deg. 16 Min. *the Apsides go backwards*, that is, 1318
move in *antecedentia* *. *1316

The Forces, upon which *the Progress* and Re- 1290
gress *of the Apsides* depend, are the Forces which 1307
disturb the Motion of the Moon, which have been 1319
before explain'd; therefore since the disturbing
Force in the Syzygies is double the disturbing
Force in the Quadratures*, the Progress, *consi-* *1296
dering one entire Revolution of the Moon, exceeds the
Regress, cæteris paribus.

In a Circle whose Center is in the Center of the Forces, the Diminution of the Force in receding from the Center produces no Effect, because in such a Line the Body does not recede from the Center; therefore the Effect of this Diminution is so much the greater, as the Curve describ'd by the Body differs more from such a Circle.

In an elliptic Orbit, one of whose Foci coin- 1320
cides with the Center of the Forces, the Curvature
in *the Apsides* differs most of all from such a Cir-
cle, and *the Effect of the Diminution of the Force, in*
receding from the Center of the Forces, is the greatest
of all; *if this Orbit is but a little eccentric at the* 1321
Ends of the lesser Axis, the Ellipse differs very little
from the Circle above-mention'd, and *the Effect*
of the Diminution is the least of all.

The

1322 The _Progress and Regress of the Apsides_ depend
upon the Proportion according to which the
Force of Gravity decreases receding from the
1315 Center of the Earth, it is therefore _the Effect of_
1316 _the Diminution of the central Force._

1323 _Plate_ XXV. _Fig._ 2.] This Motion of the _Ap-
sides_, which we have explain'd, undergoes several
Changes; _the Apsides go forward fastest of all in a
Revolution of the Moon, supposing the Line of the Ap-_
*1317 _sides in the Quadratures_*; _and in that very Case_
1322 _they go back the slowest of all in the same Revolution_*;
1320
*1318 because, by reason of the same Eccentricity of the
1321 Moon, the Quadratures are but very little di-
1322 stant from the Ends of the lesser Axis of the Orbit.

1324 _Supposing the Line of the Apsides to be in the Qua-_
*1317 _dratures, the Apsides are carried in_ consequentia _the_
1322 _least of all in the Syzygies_*, _but they return the swift-_
1321
*1318 _est in the Quadratures_*; _and in this Case, in one_
*1322 _entire Revolution of the Moon, the Regress exceeds the_
1320 _Progress._

1325 Whilst the Earth is carried along in its Orbit,
the Line of the _Apsides_ does successively go thro'
all Situations in respect of the Sun; wherefore,
considering a great many Revolutions of the Moon
*1319 _taken together, the Apsides go forwards_*; and it is
plain from Observations, that in the Space of
about 8 Years the Line of the _Apsides_ performs
one entire Revolution.

We have also said that the Eccentricity of the Orbit is not constant.

1326 _The Eccentricity of a Body is increased, if the central Force,_ the Diminution being continu'd, _decreases faster than before,_ whilst the Body is carried from the lower to the upper Apsis; for then it is every Moment less attracted, than if the Force did not decrease; and therefore it recedes the more. The Eccentricity of the Orbit is also thereby increas'd, in the same Case, in the

the Motion from the upper to the lower Apsis, because in this Case coming towards the Center, the Force increases so much the faster as the Body descends more towards the Center; so that in each Case the difference between the greatest and least distance from the Center of the Forces may become greater, and the Eccentricity be thereby increas'd. By the same Reasoning it appears that *the* 1327
Eccentricity is diminish'd when the central Force is increas'd in the motion of the Body from the lower to the upper Apsis, and likewise when that Force is diminish'd in the motion from the upper Apsis to the lower; that is, when *it decreases more slowly than before in the receding from the Center.*

Applying this to the Moon's motion, it ap- 1328
pears, that *the Eccentricity of the Orbit, every Revolution, undergoes various Changes; that it is the* 1329
greatest of all when the Line of the Apsides is in the Syzygies, because the Forces in the Apsides, being compared, do decrease faster than in an inverse
Ratio of the Square of the distance*, whence this *1298
Addition follows*, which prevails in this Posi- *1326
tion*; but *the Orbit is the least Eccentric of all* *1320
when the Line of the Apsides is in the Quadratures,
the Diminution of the Eccentricity prevailing*. *1290

We have said that the Moon moves in a Plane 1327
inclin'd to the Plane of the Ecliptic; that the 1321
Line of the Nodes is carried round in *anteceden-*
*tia**; and that the Inclination of the Orbit is not * 970
constant*; these Effects are also deduc'd from the * 969
Action of the Sun upon the Moon.

By reason of the small Inclination of the Moon's Orbit, the Forces which we have hitherto considered acting in the Plane of the Ecliptic, not regarding the Inclination of the Orbit, may (without any sensible Error) be referr'd to the Plane of the Orbit, and the Moon in it is subject to the

1330 Motions before explain'd; but *there is a Force which removes the Moon from the Plane of the Orbit**, so that we must conceive that Plane to be agitated, otherwise the Moon would go out of the Orbit.
*1314

1331 *Plate* XXV. *Fig.* 1.] Let the Moon be at F; if we attend to what has been said above concerning the Actions of the Sun*, it is plain that the Plane of the Parallelogram F H M I goes thro' the Line T S, which joins the Centers of the Earth and Sun, and therefore it is in the Plane of the Ecliptic; so that the Point N, to which is directed the Force F N, disturbing on account of the Action of the Sun, is in that Plane.
*1299

1332 *Plate* XXV. *Fig.* 4.] Let the same Force be represented by F I; at F let F R be rais'd perpendicular to the Plane of the Orbit, and imagine the Parallelogram F R I *i*, whose Side F *i* is in the Plane of the Orbit, and whose Diagonal is F I, the disturbing Force along F I is resolv'd into two in the Directions F R and F *i*, which these Lines represent*, and of which this last acts in the Plane of the Orbit; so that we must refer to this what relates to the disturbing Force, of which we have treated in N° 1299; for the Lines F *i* and F I scarce differ, and the Plane of the Parallelogram F R I *i* is perpendicular to the Plane of the Moon's Orbit.
* 192

1333 The Line F R must be determin'd, which represents the force that acts perpendicular to the Plane of the Orbit, and removes the Moon from that Plane; now the relation of the Line F R or I *i* to the Radius E T, is the Ratio of the disturbing force which is spoken of here, to the Increase of Gravity in the Quadratures*.
*1286

In

In the Case of this Figure, in which the Line of Nodes N *n* is in the Quadratures, we find out FR; because IT (which is NT of *Fig.* 1.) is given*, and because IT is to I*i* or to FR as the Radius to the Sine of the Inclination of the Orbit. 1334 *1325

But in every Case the Force must be determin'd which drives the Moon out of the Plane; let us therefore suppose the Line of Nodes carried to the Situation M*m*, whereby, every thing else remaining as before, I*i* is chang'd; to M*m* continu'd, if need be, let *i*X and IX be drawn perpendicular, which make an Angle equal to the Inclination of the Plane of the Orbit. 1335

The Ratio between ET and I*i*, that is, *the Ratio between the Addition of Gravity in the Quadratures, and the Force*, which we seek, *which removes the Moon out of its Orbit*, is compounded of the Ratios of the Line ET to TI, of the Line TI to IX, and lastly, of the Line IX to I*i*; the first is the Ratio between the Radius and 3 times the Sine of the distance of the Moon from the Quadrature*; the second is the Ratio of the Radius to the Sine of the Angle ITX, that is, of the distance of the Node from the Syzygy; lastly, the third is the Ratio of the Radius to the Sine of the Inclination of the Orbit; and the Ratio compounded of these, *is the Ratio of the Cube of the Radius to 3 times the Product of the Sines of the distances of the Moon from the Quadrature, and of the Node from the Syzygy, as also of the Inclination of the Plane.* To this Force is also to be referr'd Nº 1308. 1336 *1305

This Force vanishes in the Quadratures, because the Point I coincides with the Point T, which is the Center of the Earth, and the Line I*i* vanishes; the Lines FI and F*i* concurring in the Plane of the Orbit, which also follows from the Computation above-mention'd*; the Sine of the distance 1337 *1136

of the Moon from the Quadrature vaniſhing, and conſequently the whole Product which is multiplied by that Sine.

1338 That ſame Product vaniſhes alſo, and with it *the Force* which it repreſents, when the Sine of the diſtance of the Node from the Syzygy *vaniſhes*, that is, *ſuppoſing the Line of the Nodes in the Syzygies*. It is alſo deduc'd from this, that the Line of Nodes N *n* (*Plate* XXV. *Fig.* 5.) continu'd, goes thro' the Sun; wherefore the Sun is in the Plane of the Orbit itſelf, and therefore cannot draw the Moon but in that Plane.

1339 *The Force* alſo, *which we examine*, *is increaſed as the Moon advances towards the Syzygy, and as the*
*1336 *Node recedes from it* *.

1340 *Plate* XXV. *Fig.* 6.] Let P *p* be the Plane of the Ecliptic, P A the Orbit of the Moon; when the Moon is come to A, that is, is receded a little from the Node, it is remov'd out of the Plane of the Orbit, and in the ſecond Moment it is not carried along A B (the Continuation of the Orbit P A) but along A *b*, becauſe it comes towards the Plane of the Ecliptic along B *b*, therefore it is moved as if it came from a more diſtant Node
1341 *p*; whence it appears that *the Nodes go backward whilſt the Moon moves in its Orbit*, as long as it recedes from the Node; the Nodes alſo go back whilſt the Moon is going to the oppoſite Node, becauſe as the Moon is continually driven out of its Orbit towards the Plane of the Ecliptic, it is continually directed to a Point leſs diſtant, and comes ſooner to the Node, than if, not being agitated by ſuch a Motion, it had continu'd in motion with the ſame Celerity.

1342 *Conſidering one entire Revolution of the Moon*, cæteris paribus, *the Nodes move in* antecedentia, *ſwiftt-*
*1339 *eſt of all when the Moon is in the Syzygies**, *then ſlower and ſlower, till they are at reſt, when the Moon*
*1337 *is in the Quadratures**. Whilſt

Whilst the Earth is carried round the Sun (even when we do not attend to the above-mention'd Motion of the Nodes) *the Line of Nodes* does suc- 1343
cessively acquire all possible Situations in respect of the Sun, and *every Year goes twice thro' the Syzygies, and twice thro' the Quadratures.*

If now we consider several Revolutions of the Moon, 1344
the Nodes in one whole Revolution go back very fast, the Nodes being in the Quadratures *; *then slower,* *1339
till they come to rest, when the Line of Nodes is in the Syzygies *. *1338

By the same Force with which the Nodes are 1345
mov'd, *the Inclination of the Orbit* is also chang'd; it *is increased as the Moon recedes from the Node, and diminish'd as it comes to the Node.*

Plate XXV. *Fig.* 6.] For the Angle $b p$ L is less 1346
than the Angle A P L, and for the same Cause it is continually diminish'd, and the Inclination becomes greater; but when the Moon is come to the greatest distance from the Plane of the Ecliptic, and is going towards the opposite Node, the Direction of the Moon is continually inflected towards the Plane of the Ecliptic, and less inclin'd to it than if it continu'd in motion in its Orbit; let N $p n$ be the Plane of the Ecliptic, the Curve N n the Orbit of the Moon, by the force whereby the Moon is continually remov'd out of it, the Way of the Moon is chang'd, and it goes in the Curve N p, which is more inclin'd to N $p n$ at N than at p; so that we must conceive the Inclination of the Plane of the Orbit to be twice changed * whilst the Moon moves from one Node to *1314
the other, therefore this happens four times; *in each Revolution of the Moon it is twice diminish'd,* 1347
and twice again increased.

Plate XXV. *Fig.* 4.] *Supposing the Nodes* N n 1348
to be *in the Quadratures,* the Forces which *in one Revolution* increase *the Inclination* and diminish it

are equal to one another, for by reaſon of the
equal diſtance of each Node from the Syzygies,
the Forces that change the Inclination at ND
and *n*E are equal to the Forces in the correſpon-
*1336 dent Points in the Arcs D*n* and EN*; by the
former the Inclination is increaſed, by the latter
1345 it is diminiſh'd; the Diminution of the Angle
of Inclination, on account of the firſt, is reſtor'd
by the Action of the ſecond; and here it *is not*
*1343 *chang'd*. In the Motion above-mention'd* of the
Line of Nodes in reſpect to the Sun, which de-
pends upon the parallel Situation of this Line, the
Node N is carried to the Syzygy E. When (*for
Ex.*) the Line of Nodes is come to the Situation
M*m*, the Moon in its Receſs from the Nodes
goes thro' the Quadratures N*n*, in which the
1337 Force which changes the Inclination vaniſhes,
1336 and near which it is the leaſt of all; but in co-
ming towards the Nodes, the Moon is every where
diſtant from the Quadratures, and a greater force
1336 acts upon it; therefore *conſidering one entire Re-*
1349 *volution*, the Increaſe of the Angle of Inclination
1345 exceeds its Diminution; that is, that Angle is
increaſed, or which is the ſame, *the Inclination is
diminiſh'd*; which obtains every where *in the Mo-
tion of the Nodes from the Quadratures to the Syzy-
gies.*

1350 *When the Nodes are come to the Syzygies, the In-*
1351 *clination of the Plane of the Orbit is the leaſt of all*;
for *in the Motion of the Nodes from the Syzygies to the
Quadratures*, the Plane of the Orbit is continually
more and more inclin'd; for in that Caſe, as the
Moon goes to the Node, it paſſes thro' the Qua-
dratures; in its Receſs from them the Moon is
diſtant from the Quadratures, and *in one whole
Revolution of the Moon*, the Force which increaſes
1337 the Inclination, exceeds that which diminiſhes
1345 it, therefore *the Inclination is increaſed*; and *it is*
1352 *all.*

the

the greatest of all when the Nodes are in the Quadratures, where the Diminution of the Angle made by the Plane of the Orbit with the Plane of the Ecliptic is terminated*. *1349

All the Errors in the Moon's Motion, that we have 1353
explain'd, _are something greater in the Conjunction than in the Opposition_*. *1295

All the disturbing Forces are determin'd by disco- 1354
vering their relation with the Addition of Gravity
in the Quadratures*, for which reason they all *1306
undergo the same Changes as that Addition does, 1307
that is, they _are inversly as the Cube of the distance_ 1336
_of the Sun from the Earth_*, _which, when it remains_ *1289
the same, they are as the distance of the Moon from
_the Earth_*. _Considering all the disturbing Forces to-_ *1288
_gether, the Diminution of Gravity prevails_*, which 1355
follows immediately from the Progress of the Ap- *1296
sides; for it appears from thence, that consider- * 970
ing several Revolutions together, the Effect of 1325
the Diminution of Gravity exceeds the Effect of *1317
the Increase of it*. 1318

Therefore _the Motion of the Moon being consider'd_ 1356
in general, the Gravity of the Moon towards the Earth
_is diminish'd coming near the Sun_*; therefore when *1355
it is less attracted by the Earth, it recedes more 1354
from it than it would recede if there was no such Diminution of Gravity; therefore in that Case
the Moon's distance is increas'd, as also _the perio-_ 1357
_dical Time_*; and that Time _is the greatest, as also_ * 224
the distance of the Moon (cæteris paribus) _the great-_
_est when the Earth is in the Perihelion_*, because *1354
then it is least distant from the Sun.

CHAP. XVII.

Concerning the Figures of the Planets.

IF we consider the Figures of the Planets, we shall find that they have such Figures which

follow from these very Laws by which the System is govern'd, which is very agreeable to that admirable Order which we observe every where, that no Forces act upon the Planets to destroy
1358 them; that is, that *the Figure of a Planet, whether it be a primary or secondary Planet, is such as it would acquire if it wholly consisted of fluid Matter*; which agrees with the Phænomena.

1359 Whence it follows that *all the primary and secondary Planets are spherical*, for they consist of a Matter whose Particles gravitate towards one ano-
1206 ther; from which mutual Attraction a spherical
1207 Figure is generated, in the same manner as a Drop becomes round from another sort of Attraction
* 34 of the Parts*.

1360 *This spherical Figure of the Planets is not chang'd from their motion round the Sun, or from the motion of the secondary Planets about their primary ones*, because all the Particles are carried by the same motion; but this Figure undergoes some Change by the motion round the Axis, and so much the greater as this motion is swifter.

1361 *Plate* XXV. *Fig.* 7.] Let P P be the Axis of a Planet, E *e* the Diameter of the Equator, perpendicular to the Axis; let there be a Canal P C E fill'd with a Liquid; this Fluid will descend by its Gravity in both Legs towards C, and will not be at rest till the Pressure in both Legs be equal; if the Planet be at rest, the height of the Fluid in
1359 both Legs will be equal; but if the Planet be mov'd about its Axis P *p*, all the Liquid in the Leg C E will endeavour to recede from the Cen-
* 217 ter by its centrifugal Force*, which Force acts
* 223 contrary to Gravity*, and therefore diminishes the Gravity; so that there is no *Equilibrium* till C E exceeds C P: Now if the Canal be taken away, the lateral Pressure of the Fluid, of which the Planet consists, does not change the Gravity

towards

towards C, nor the difference between the heights of the Columns CE CP*; therefore the Planet is every where higher in the Equator than in the Poles, and *acquires, by its motion round its Axis, the Figure of a Spheroid depress'd in its Poles*; for the Elevation is continually diminish'd as you go towards the Pole, because the centrifugal Force is diminish'd by reason of the Diminution of the distance from the Axis*. * 280 1362 * 232

If what has been demonstrated be compar'd with the Phænomena, it will appear why all the Bodies in our System are spherical*; but that this Figure is not exact, but a little chang'd by their motion round their Axis*, tho' this cannot be observ'd in most of them, may be deduc'd from Observations made upon *Jupiter* and the Earth. *Astronomers have observ'd that the Axis of* Jupiter *is shorter than its equatorial Diameter*; altho' this Planet be the greatest of all the Planets, it is moved the swiftest about its Axis*, and therefore this difference may be observ'd. * 924 * 1362 1363 * 962

1364 *The Elevation of the Earth at the Equator is determin'd by us*, altho' perhaps to the Inhabitants of the other Planets, if there are any, it may not be more sensible than the Elevations on *Mars* and *Venus* are to us, which are so small that we cannot perceive them.

1365 Suppose the Earth to be fluid, it will acquire the aforesaid spheroidical Figure*; if the Parts cohere towards the Center, the Position of the other Parts will not be chang'd thereby, nor will it be chang'd if in some Places the Parts cohere together quite to the Surface; so that the Surface of the Sea must necessarily acquire a spheroidical Figure depress'd at the Poles. But since the Shores are every where but a little elevated above the Surface of the Sea, it is certain that the Continent acquires the same Figure. * 1362

Now

Now to measure this Elevation, that is, how much the Diameter of the Equator of the Earth is longer than the Axis, we must consider its motion round its Axis in the Space of 23 Hours,
* 960 56 Min. 4 Sec.* and supposing the Earth homogeneous, the Computation will be made in the following manner.

1366 The Periphery of the Earth is 128,202,185 *Rhynland* Feet, therefore in one Second of Time a Point of the Equator goes thro' 1488 Feet; the versed Sine of which Arc is 0,054, a Space which could be gone thro' by a Body in such a Time by the centrifugal Force.

By Gravity a Body in one Second, as we have shewn before, falls thro' 15,607 *Rhynland* Feet; but these Experiments were made at the distance of 48 Deg. from the Equator E *e* (*Plate* XXV. *Fig.* 7.) at the Point A; the centrifugal Force at E is to the centrifugal Force at A as CE to CA,
* 232 for these Lines are very little different at AB*; let this centrifugal Force be A *b*, having drawn the Perpendicular *b a* to C A continu'd, let the Force thro' A *b* be resolv'd into two other Forces
* 192 directed along A *a* and *a b**, the Gravity is diminish'd only by the former, and A *b* is to the Force diminishing it as C A to A B, by reason of the similar rectangular Triangles A *b a* and A B C, which have their opposite vertical Angles equal at A; therefore the centrifugal Force at the Equator, with which a Body in one Second goes thro' 0,054, is to the Force which diminishes the Gravity at A, in a duplicate Proportion of the Radius A C to A B, which is the Cosine of the Latitude A E of 48 Degrees; so that from this diminishing Force the Body in one Second goes thro' 0,0243; wherefore if the Earth was at rest, in falling it would not go through 15,607 Feet, but 15,632; with which Gravity

a Body

a Body falls under the Poles, because these Points
are not mov'd; at the Equator, by the centrifugal Force, a Body goes thro' 0,054, and falls as
much in the same Time from the Height of
15,578 Feet; whence it appears that the Gravity under the Poles is to the Gravity under the
Equator as 289 to 288.

If *Fig.* 7. represents the Figure of the Earth,
the Weight of a Column of Liquid CE will be
to the Weight of a Column of Liquid CA, the
Earth being at rest, as 289 to 288; for otherwise,
the Earth moving, there will not be an *Equilibrium*, because $\frac{1}{289}$ of the Column CE is sustain'd by
the centrifugal Force; for the centrifugal Force
decreases as you come towards the Center, in the
Ratio of the distance*, in which Ratio also the * 232
Gravity decreases*; so that in all the Points of *1233
the Column the same Part of the Weight is sustain'd as towards the Surface.

Whence we deduce, that *the height* CP *at the* 1367
Pole is to the height EC *at the Equator as* 229 *to*
230; for supposing this Ratio between the Axis
and the equatorial Diameter, if a Computation be
made of the Gravities in the Places P and E, the
Earth being at rest, they are found to be to one
another as 1121,71. to 1120,71; which Ratio
obtains every where in correspondent Points, that
is, which are distant from the Center as CP to
PE, because in both Legs the Gravity decreases
in proportion to the distance from the Center*; *1233
you have the Weight by multiplying the Quantity of Matter by the Gravity, for the Weight
increases in a Ratio of both; by multiplying
1121,71. by 229, and 1120,71. by 230, the Products are to one another as 288 to 289, which is
the Ratio of the Weights before discover'd; the
mean Diameter of the Earth is 3,400,669 Perches*,

* 976 ches*, therefore the Axis P P is 3,393,261, and the equatorial Diameter E *e* is 3,408,078 Perches, which exceeds the Axis by 14,817 Perches (*viz.*)
1368 $\frac{1}{230}$, and *the Equator is more elevated by* 7408,5.

1369 In this Computation, as we have said, we have look'd upon the Earth as homogeneous; but if it be more dense towards the Center, the Matter which is added to it may be look'd upon as a separate Body, from whose Center the Points P and E are unequally distant, and towards which therefore the Bodies P and E have a different Gravi-
1226 ty; and the difference is so much the greater as these differences are greater; and it will be also so much the greater in respect of the whole Gravity, as the Quantity of Matter which is added, or which is the same, as the Density is greater towards the Center.

It is plain that the Forces of Gravity at the Poles and the Equator differ from one another more than $\frac{1}{229}$ Part, by comparing together Experiments made at several Distances from the Equator by the help of Pendulums, by which the Forces of Gravity may be compar'd together, as
* 164 we have shewn*, and which difference is truly
165 nearly double that which is found by Computa-
1370 tion; whence it follows, that *the Elevation of the Equator is nearly double that which we have deter-*
*1368 *min'd to be 7408,5 Perches**.

Now if we consider the spheroidical Figure of
1371 the Earth, we shall see that *heavy Bodies do not tend directly to the Earth's Center*, unless at the Poles and the Equator, *but every where perpendicularly to the Surface* of the Spheroid; for a Liquid will not be at rest unless its upper Surface forms a right
* 272 Angle with the Direction of heavy Bodies*; and the Figure of a Spheroid is form'd by the Surface of a quiescent Fluid. We also deduce this Direction

ction of heavy Bodies from the centrifugal Force. 1372
(*Plate* XXV. *Fig.* 7.) the Body A by its Gravity tends towards C, and is carried by its centrifugal Force along A *b*; this Force at the Point A is to the Gravity along A C as 1 to 430,8. having formed a Parallelogram with the Sides A *c* and A *b*, supposing these to one another as 430,8. to 1, the Diagonal will shew the Direction of heavy Bodies*, forming a small Angle with the Line A C. The Force along A *b* increases as you go towards the Equator, whereby this Angle is increas'd, but is diminish'd by the Increase of the Angle C A *b*; so that in the Equator, where the centrifugal Force is greatest, the Direction of heavy Bodies coincides with E C; at the Pole it coincides with P C, because there is no centrifugal Force there.

* 190

In this spheroidical Figure *the Latitude of the Place is determin'd by an Angle*, as ACE, *which is made with the Equator by a Line drawn from the Place of the Center:* Dividing this whole Arc PAE by this Method into 90 Parts, that is, into Degrees, it will easily appear, that *going towards the Poles the Degrees are increased on the Surface*; but this difference is so very small, that in measuring Degrees that are not very distant, it cannot be discover'd; because the Error, arising from the Make and Use of the Instruments, exceeds this difference; whence Degrees measur'd at the South and North of *France*, as also in *England*, differ little from one another, and the middle one is the least of all; wherefore *nothing can be concluded concerning the Earth's Figure from* these Measures. 1373 1374 1375

CHAP.

CHAP. XVIII.

The physical Explanation of the Motion of the Axis of the Earth.

THAT the Nodes of the Moon go back,
*1341 that is, are mov'd in *antecedentia* *, and that
1347 the Inclination of its Orbit is liable to change,
we have already demonstrated; let us conceive
several Moons to be at the same distance, revol-
ving in equal Times about the Earth, in a Plane
inclin'd to the Plane of the Ecliptic, it is plain
they will all be agitated by the same Motions;
let us conceive the Number of the Moons to be
increas'd, so as to touch one another, and form
a Ring, whose Parts cohere; whilst one part of
the Ring is attracted, to increase the Inclination,
1376 the other part is agitated by a contrary motion,
1345 to diminish its Inclination; the greater Force
1377 in this Case prevails, that is, *in the motion of the
Line of Nodes, from the Quadratures towards the
Syzygies, the Inclination of the Ring is diminish'd in
1349 each of its Revolutions *, and it is the least of all when
1350 the Line of Nodes is in the Syzygies; on the contra-
ry, *its Inclination is increas'd when the Line of Nodes
is carried from the Syzygies towards the Quadra-
1351 tures *, and it is the greatest of all when the Line of
1378 the Nodes is in these last* *; the Line of the Nodes is
1352 continually carried in antecedentia, *unless when it is
1341 at rest in the Syzygies *.
1344

379 *If the Quantity of Matter in the Ring be dimi-
nish'd, its Motions will not be chang'd*, because they
depend upon Gravity, which acts equally upon
1027 every Particle of Matter.

If

If the Diameter of the Ring be diminish'd, these 1380
Motions are diminish'd in a Ratio of this Diminution*, but none of them wholly vanish; and *1354
it is agitated by the same Motions.

Let us conceive the Earth to be spherical; and 1381
in the Plane of the Equator, which makes an Angle of 23 Deg. 29 Min. with the Plane of the Ecliptic, let there be a Ring, revolving in the same Time as the Earth; let it be diminish'd so as to touch the Earth, and cohere with it; by this the aforesaid motion of the Ring will not be destroy'd; for since the Earth is kept in a determinate Situation by no Force, it yields to the Impressions of the Ring, whose Agitations are yet diminish'd, the Matter to be mov'd being increas'd, and the moving Power remaining the same.

And this is truly the Case; for the Figure of the Earth is spherical, encompass'd with a Ring at the Equator, whereby the Earth is more elevated towards the Equator*, the Line of Nodes *1370
of which Ring is the Section of the Planes of the Equator and Ecliptic; whence we deduce the following Conclusions.

In the Equinoxes the Inclination of the Equator 1382
is least of all*, and therefore *the Inclination of the* *1377
Axis is the greatest, for it makes a right Angle
with the Plane of the Equator*; the Inclination *1075
of the Equator is increas'd, that is, *the Inclination*
of the Axis is diminish'd till the Sun comes to the Sol- 1383
stices, where this Inclination of the Axis is least of
all, and that of the Equator the greatest*; there- *1377
fore *twice in a Year the Inclination of the Axis of the*
Earth is diminish'd, and twice increas'd; and *the* 1384
Section of the Plane of the Equator with the Plane of 1385
the Ecliptic, which *is at rest in the Equinoxes, the*
rest of the Time is mov'd in antecedentia*. *1378

The

1386 The Plane of the Equator is inclin'd to the Plane of the Moon's Orbit, for it makes a ſmall
* 969 Angle with the Plane of the Ecliptic*, and therefore the Moon acts in the ſame manner upon the Ring as the Sun; and altho' the Moon be leſs, yet becauſe it is much leſs diſtant than the Sun, it exerts a greater Action upon the Ring; wherefore
1387 alſo *the Inclination of the Axis of the Earth to the*
*1384 *Plane* of the Moon's Orbit* (and conſequently to the Plane *of the Ecliptic*) *is twice chang'd in every Revolution, and twice reſtor'd by the Action of the Moon*; *and the Section of the Plane of the Equator*
*1385 with the Plane of the Moon's Orbit * *is carried in antecedentia*; from which Motion neceſſarily follows, that the Section of the Plane of the Equator *with the Plane of the Ecliptic changes its Place.*

1388 *The Changes of the Inclination of the Axis are too ſmall to be obſerv'd, but the change of Place of the*
1389 *Line of the Equinoxes, and the motion of the Axis* which follows from it, being always carried the ſame way, *at laſt become ſenſible*; and from theſe
1185 follow the Phænomena before explain'd.
1186

CHAP. XIX.

Concerning the Tides.

THAT we may explain the Tides from the Principles already laid down, we muſt conſider, that the Earth, as alſo all Bodies near it,
*1206 gravitate towards the Moon *; therefore the Particles of Water in the Earth's Surface which tend towards the Center of the Earth (for here we neglect the Conſideration of N° 1371.) are carried with it towards the Moon. Since alſo the ſolid Maſs of the Earth is carried towards the Moon, according to the Laws, which would obtain,

obtain, if all the Matter of which it consists was collected in its Center*, *what has been demonstra-* *1126
ted in Chap. 16. *of the Action of the Sun upon the Moon* falling towards the Earth, whilst with the 1390
Earth it goes towards the Sun, *may be applied to the Action of the Moon upon the Particles of Water in the Earth's Surface*, which do not cohere with the Mass of the Earth, but tend towards its Center, and continually with its Mass fall towards the Moon; by which Force, as we have shewn*, the *1280
Earth is kept in its Orbit, about the common Center of Gravity of the Earth and the Moon.

Plate XXV. *Fig.* 1.] Let S be the Moon, 1391
A L B L *l* the Surface of the Earth, whose Mass tends towards the Moon, as if it was all collected at T; by the Action of the Moon, the Particles of Water A and B acquire a greater Gravity towards T*; on the contrary, the Particles at L *l* *1287
lose of their Gravity*; whence we deduce, that *1296
if the whole Earth was cover'd with Water there would not be an *Equilibrium*, unless this Water was more elevated in the Points L and *l*, than in a whole Circle 90 Degrees distant from these Points, and therefore passing thro' the Points A and B; therefore *by the Action of the Moon the Wa-* 1392
ter acquires a spheroidical Figure, formed by the Revolution of an Oval about its greater Axis, which being continu'd, goes thro' the Moon.

Let us suppose the Moon in the Equator, all the Sections of the Earth, which are parallel to the Equator, as they are also parallel to the Axis of the Spheroid*, are oval, whose greater Axes *1392
pass thro' the Meridian of the Moon; whence it follows, that *the Earth being at rest in any Circle* 1393
of Latitude, the Water is more elevated in the Meridian in which the Moon is, and in the opposite Meridian, than in the intermediate Places.

DEFINITION.

1394 The lunar Day *is the Time ſpent between the Moon's going from the Meridian and coming to it again*; this Day is divided into 24 lunar Hours, it is 50 Minutes longer than the natural Day.

From the Motion of the Earth round its Axis every lunar Day, every Place paſſes thro' the Meridian of the Moon and the oppoſite Meridian, that is, twice paſſes thro' that Place where
1395 the Water is raiſed *by the Action of the Moon*, and twice thro' that Place where the Water is diſper-
1393 ſed by the ſame Action; and ſo *in a lunar Day the Sea is twice elevated and twice depreſſed in any aſſign'd Place.*

1396 By the Motion of the Earth round its Axis, the elevated Water continually recedes from the Meridian of the Moon; yet by the Action of the Moon the Axis of the Spheroid paſſes thro' the
1392 Moon; therefore the Water is continually agitated, that the Elevation, which (on account of the Motion of the Earth) is remov'd, may be brought under the Moon; therefore the Water continually flows from A and B (*Plate* XXV. *Fig.* 1.) towards L and *l*, whilſt by the Motion of the Earth the Elevation is carried from L towards B, and from *l* towards A; that is, between L and B, as alſo between *l* and A, there are two contrary Motions, by which the Water is accumulated; ſo that the greateſt Elevations are between theſe Points (*viz.*) not directly under the Moon, but on one ſide of that Point, and likewiſe aſide of the oppoſite Point; that is, in any
1397 Place *the Water moſt elevated two or three Hours after the Moon has paſſed the Meridian of the Place, or the oppoſite Meridian.*

The

The Elevation towards the Moon a little exceeds 1398
*the opposite one** ; *the Ascent of the Water is dimi-* *1390
nish'd as you go towards the Poles, because there is no 1295
Agitation of the Water there.

What has been demonstrated in relation to the 1399
Moon, may be applied to the Sun ; therefore *from* 1400
the Action of the Sun every natural Day, the Sea is 1401
*twice elevated and twice depressed** ; *this Agitation* *1395
is much less, on account of the immense distance
of the Sun, *than that which depends upon the Moon*,
yet *it is subject to the same Laws*. 1402

The Motions which depend *upon the Actions of* 1403
the Moon and Sun, are not distinguish'd, but con-
founded ; and from the Action of the Sun *the lu-
nar Tide is only chang'd* ; *which Change varies every
Day*, by reason of the Inequality between the na- 1404
tural and lunar Day*. *1394

In the Syzygies the Elevation from the Actions 1405
of both Luminaries concur, and *the Sea is more
elevated* ; *the Sea ascends less in the Quadratures*,
for where the Water is elevated by the Action of
the Moon, it is dispersed by the Action of the
Sun, and so on the contrary ; therefore *whilst the* 1406
*Moon passes from the Syzygy to the Quadrature, the
daily Elevations are continually diminish'd* ; on the
contrary, *they are increas'd when the Moon moves
the Quadrature to the Syzygy* : *At a New-moon also*, 1407
cæteris paribus, *the Elevations are greater* ; *and
those that follow one another the same Day, are more
different than at a Full-moon**. *1398
1402

The greatest and least Elevations are not observ'd 1408
*till the second or third Day after the New or Full-
moon*, because the Motion acquir'd is not pre-
sently destroy'd from the Attrition, and other
Causes, by which acquir'd Motion the Ascent of
the Water is increas'd ; altho' the Action by
which the Sea is raised be diminish'd, somewhat

like to what we have demonſtrated elſewhere concerning Heat*.
*1174

1409 If now we conſider the Luminaries receding from the Plane of the Equator, we ſhall perceive that *the Agitation* is diminiſh'd, and *becomes leſs, according as the Declination of the Luminaries becomes greater*; which plainly appears, if we conceive them to be in the Poles, for then the Axis of the ſpheroidical Figure coincides with the Action of the Earth; and all the Sections that are parallel to the Equator, are perpendicular to the Axis of the Spheroid, and therefore circular; ſo that the Water in every Circle of Latitude will have every where the ſame Elevation; and ſo in the Motion of the Earth, the height of the Sea is not chang'd in particular Places. If the Luminaries recede from the Poles, it is eaſy to find that the Agitation will be more and more increas'd, till it be the greateſt of all, the Spheroid revolving about a Line perpendicular to the Axis, the Axis of the Spheroid being ſuppoſed in the Plane of the Equator.

1410 Hence it is plain, why *in the Syzygies, near the Equinoxes, the Tides are obſerv'd to be the greateſt*, both Luminaries being in or near the Equator.

1411 *The Actions of the Moon and Sun are greater, the leſs thoſe Bodies are diſtant from the Earth**; but when the Diſtance of the Sun is leſs, and it is in the South Signs, often both the greateſt equinoctial Tides are obſerv'd in that Situation of the Sun; that is, before the vernal, and after the autumnal Equinox, which yet does not happen every Year, becauſe ſome Variation may ariſe from the Situation of the Moon's Orbit, and the diſtance of the Syzygy from the Equinox.
*1354
*1390

Plate XXV. *Fig.* 8.] *In Places distant from the Equator, as the Luminaries recede from the Equator, the Elevations that happen the same Day are unequal.* Let P P be the Axis of the Earth, E E the Equator, L *l* a Circle of Latitude, A B the Axis of the spheroidical Figure which the Water forms; when a Place in the Circle L *l* is given at L or *l*, it is given in the same Meridian with the Axis of the Spheroid, and the Water is most elevated in both Cases; yet at L it is more elevated than at *l*, for C l exceeds C *l*; which Lines measure the Heights of the Waters, that is, the Distances from the Center; these Lines would be equal if A L and B *l* (which are the Distances from the Axis of the Spheroid) were equal; but C *l* is less, because B *l* exceeds A L, which arises from the Inclination of the Axis of the Spheroid to the Equator. 1412

As long as the Moon is on the same side of the Equator in any Place, that is, towards the Line C A continu'd, *the Elevation of the Water is observ'd to be greatest every Day after the Moon has passed the Meridian of the Place*, for there is the greatest Elevation when the Place is come to L; but *if the Equator* separates, or *is between* the *Moon and the Place* of which we speak, that is, if the Moon be towards the Line C B continu'd, the Water again at L will come to the greatest height, and *every Day the greatest Elevation of the Sea will be after the Moon has passed thro' the opposite Meridian.* 1413 1414

All things which have been hitherto explain'd, would exactly obtain, if the whole Surface of the Earth was cover'd with Sea; but since the Sea is not every where, some Changes arise from thence, not indeed in the open Sea, because the Ocean is extended enough to be subject to the

Motions we have spoken of; but *the Situation of*
1415 *the Shores, the Streights, and many other things, depending upon the particular Situation of the Places, disturb these general Rules*; yet it is plain from the most general Observations, that the Tide follows the Laws which we have explain'd. What remains is, to determine the Forces with which the Sun and Moon act upon the Sea, that it may appear that they are able to produce the Effects which we have mention'd; and that the Actions of those Bodies upon Pendulums and other Bodies are insensible.

1416 The Increase or Addition to the Gravity of the Moon in the Quadratures from the Action of the Sun, is to the Gravity of the Moon towards the
1291 Earth as 1 to 178,73; in which Computation we have suppos'd the mean distance of the Moon from the Center of the Earth to be 60 Semidia-
1285 meters of the Earth; therefore the Gravity of the Moon is to the Gravity of the Earth's Surface
1208 as 1 to $60 \times 60 = 3600$; therefore the above-mention'd Increase is to the Gravity on the Earth's Surface as 1 to 643428; in which Computation there is an Error to be corrected.

This Computation would be exact, if the Increase of which we speak, was to the Force with which the Earth descends towards the Sun, as the distance of the Moon (which is 60 Semidiameters of the Earth) to the distance of the Earth from
1287 the Sun; but it is as the true mean distance of the Moon, which is $60\frac{1}{2}$ Semidiameters of the Earth to the distance of the Earth from the Sun; wherefore the Increase that we have just determin'd ought to be $\frac{1}{120}$ Part increased, and will be to the force of Gravity on the Earth's Surface as $1\frac{1}{120}$ to 643428, or as 1 to 638110,4.

This Increase of the Gravity of the Moon in the Quadratures from the Action of the Sun, is to

to the Increase of the Gravity of the Water on the Earth's Surface, in Places which are 90 Deg. distant from the Sun (from the same Action of the Sun) as 60 ½ to 1 * ; therefore this Increase of *1288
the Gravity is to the Gravity of the Water as 1 to 38605679. The Diminution of the Gravity under the Sun, and in the opposite Place, is double this Increase* ; therefore it is to the Gravity as 1 *1296
to 1930839 ; and *the* whole *Change in the Gravity* 1417
arising from the Action of the Sun, is to the Gravity itself as 1 *to* 12868560.

In order to compare the Action of the Moon 1418
with the Action of the Sun, we must make Experiments in Places, in which, by reason of the Narrowness, the Sea is sensibly raised. Near *Bristol*, at the Autumn and Spring, at which Times the Agitation of the Sea is greatest*, the Water *1410
ascends in the Syzygies about 45 Feet, more or less ; in the Quadratures about 25 Feet, more or less ; which Numbers are to one another as 9 to 4.

The Determination of the Forces, which we would find, if the greatest and least Elevations were exactly at the Time of the Syzygies, would be very easy, which we have shewn before not to happen so*. *1408

The distance of the Moon from the Syzygy or the Quadrature is not always the same in the greatest or least Elevation, for this distance varies, because the Moon is sometimes more, and sometimes less distant from the Meridian, when it goes thro' the Syzygy or Quadrature ; the mean distance of the Moon from the Syzygy or Quadrature, to which the aforesaid Observations ought to be referr'd, is about 18 Deg. 30 Min. so that the whole Action of the Sun neither conspires with the Action of the Moon in the Syzygies, nor acts contrary to it in the Quadratures ; also in

in ſuch a Caſe, if at the Syzygy both the Luminaries be in the Equator, in the ſaid diſtance from the Quadrature, the Declination of the Moon is 22 Deg. 13 Min. more or leſs, whereby the force
1409 of the Moon to move the Sea is diminiſh'd; beſides, *cæteris paribus*, the diſtance of the Moon from the Earth at the Syzygies is leſs than at the
1310 Quadratures, whence alſo the Action of the
1311
1411 Moon is diminiſh'd at the Quadratures; by attending to all which things we may diſcover, that
1419 *the mean Force of the Sun to move the Sea, is to the mean Force of the Moon to move the ſame, as* 1 *to* 4,4815; but the Force of the Sun is to the Force
1417 of Gravity as 1 to 12868560; wherefore *the Force of the Moon is to the ſame Force of Gravity as*
1420 1 *to* 2871485; from whence it follows, that theſe Forces of the Moon and Sun are too ſmall to be ſenſible in Pendulums, and other Experiments; but it is eaſily prov'd that they are capable of agitating the Sea.

By diminiſhing the Gravity $\frac{1}{289}$ Part, the Sea
*1368 is raiſed to the height of 88902 *Rhynland* Feet*,
1417 for each Perch contains 12 Feet; whence, by the
1421 Rule of Proportion*, we find, that *the Action of*
1422 *the Sun changes the height of the Sea two Feet, and*
*1419 *that the Action of the Moon changes it* 8,95*; *and that from the join'd Action of both, the mean Agitation is of about* 11 *Feet*, which agrees pretty well with
1423 Obſervations; for in the open Ocean, as the Sea is more or leſs open, the Water is raiſed to the height of 6, 9, 12, or 15 Feet; in which Elevations alſo there is a difference ariſing from the Depth of the Waters; but thoſe Elevations,
1424 which far exceed theſe, happen *where the Sea violently enters into Streights or Gulfs, where the Force is not broken till the Water riſes higher.*

CHAP.

CHAP. XX.

Of the Moon's Denſity and Figure.

THE Forces of the Sun and Moon for giving motion to the Sea, are to one another in a Ratio compounded of the Ratio of the Quantities of Matter in theſe Bodies* (for all the Particles of Matter act) and the inverſe Ratio of the Cubes of the Diſtances of the Sun and Moon from the Earth*. 1425 *1207 *1390

The Quantities of Matter are in a Ratio compounded of the Ratio of the Bulks, that is, of the Cubes of the Diameters and the Ratio of the Denſities*; wherefore the Forces above-mention'd are directly as the Denſities and the Cubes of the Diameters, and inverſly as the Cubes of the Diſtances. 1402 1354 * 288 79

The apparent Diameters of Bodies, that is, the Angles under which they are ſeen, increaſe as the Diameters themſelves, and diminiſh as the Diſtances; that is, they are directly as the Diameters, and inverſly as the Diſtances; therefore the Ratio compounded of the Ratio's of the Cubes of the apparent Diameters *of the Sun and Moon*, and of the Ratio of the Denſities, will be the Ratio of the Forces whereby thoſe Bodies act upon the Sea; therefore the *Denſities* of thoſe Bodies *are directly as the Forces whereby they move the Sea, and inverſly as the Cubes of their apparent Diameters*; and dividing the Forces by the Cubes of thoſe Diameters, you have the Ratio of the Denſities. 1426

The

The Force of the Sun is to the Force of the
1419 Moon as 1 to 4,4815; the mean apparent Diameter of the Sun is 32 Min. 12 Sec. and the mean apparent Diameter of the Moon is 31 Min. 16½ Sec. that is, they are to one another as 3864 to
1427 3753; therefore *the Density of the Sun is to the Moon's Density as* 10000 *to* 48911; which Density of the Moon may be compar'd with the Den-
*1260 sities of *Jupiter*, *Saturn*, and the Earth*; and the Moon is denser than the Earth.

The Quantities of Matter in two Bodies are to one another in a Ratio compounded of the Densi-
* 79 ties and Bulks*; that is, if the Body be a Sphere, in a Ratio compounded of the Densities and the Cubes of the Diameters.

1428 *The Densities of the Moon and Earth are to one*
*1427 *another as* 48911 to 39214*, the Diameters as 11
1260 to 40,2. therefore the *Quantities of Matter* in those Bodies *are as* 1 *to* 39,13. Tho' the Densities be discover'd, if you suppose the Bodies to be homogeneous, yet the Quantities of Matter will be rightly defin'd tho' the Bodies are not homogeneous; for we determine the Density which that Body would have, if the Matter of which the Body really consists was equally diffus'd all over it.

1429 *The Gravities on the Surfaces of the Earth and Moon* are determin'd by multiplying the Densities
1230 by the Diameters, that is, they are to one another as 2,93 to 1, or as 407,8 to 139,2; which Number also does express the relation of Gravity on the Surface of the Moon with the Gravity
*1258 on the Surfaces of the *Sun*, *Jupiter*, and *Saturn**.

1430 *The common Center of Gravity of the Moon and Earth*, about which both Bodies are mov'd, is determin'd; for its distance from the Center of the Earth, *is to the distance* between the Centers

of

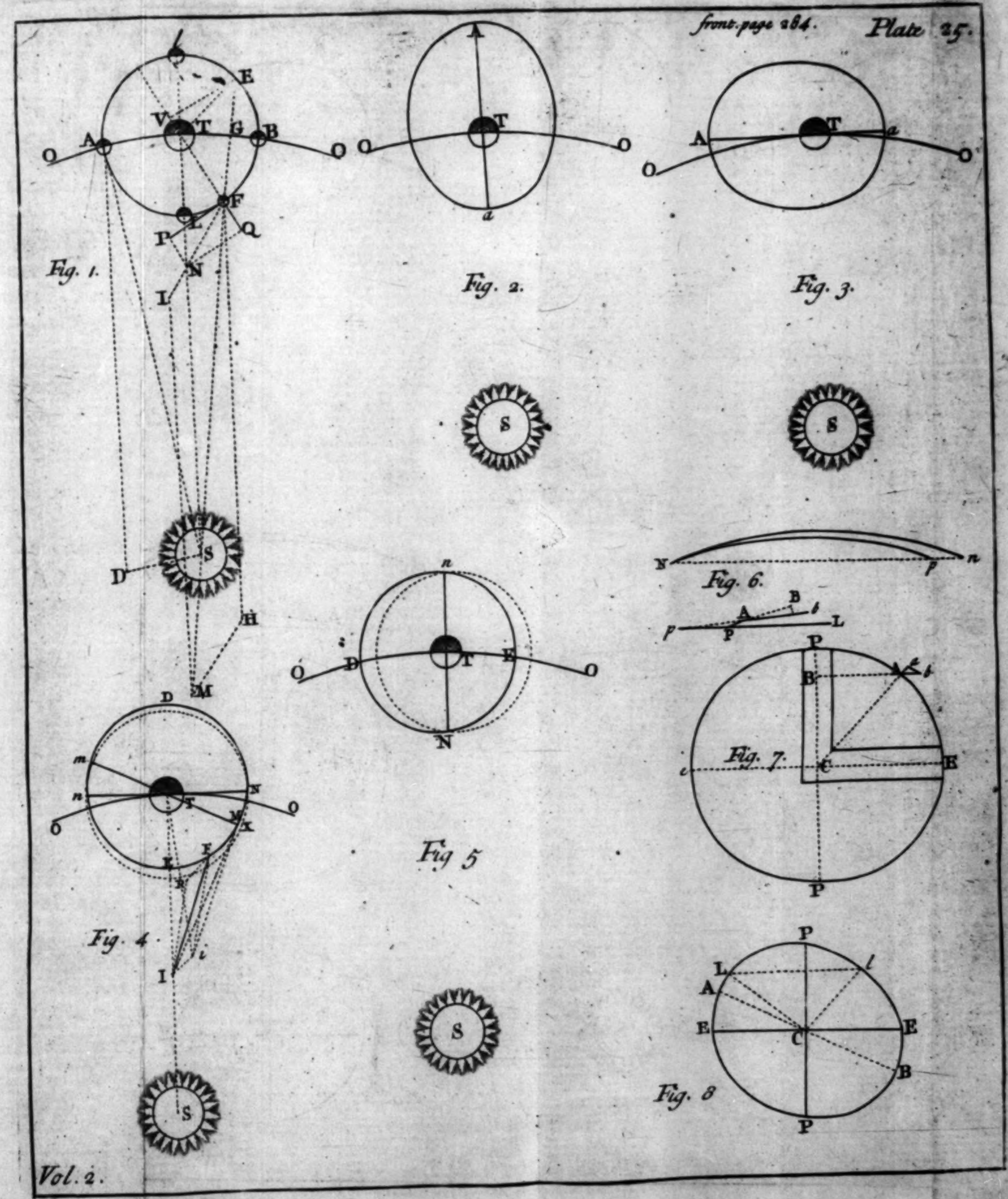
of both Bodies, as the Quantity of Matter in the Moon to the Quantity of Matter in both Bodies*; * 234
therefore 40,13 is to 1 as the distance of the Moon 235
from the Earth, is to the requir'd distance of the Center of Gravity *from the Center of the Earth*, which is found to be of 5126950 Perches, as is deduc'd from the known Diameter of the Earth* * 976
and the distance of the Moon.

To determine the Figure of the Moon, we must 1431
examine what Figure it would have if it was fluid*. If we consider the Moon alone at rest, it *1358
would be spherical*; if we consider the Action *1359
of the Earth upon the Moon, the Moon would acquire the Figure of a Spheroid, whose Axis would go thro' the Earth*. The Force of the *1392
Earth for changing the Figure of the Moon, is to the Force of the Moon upon the Earth as 39,13 to 1*, and as the Diameter of the Moon *1428
to the Earth's Diameter*, which are to one ano- 1207 *1390
ther as 11 to 40,2; and it is a Ratio compound- 1354
ed of these 10,7 to 1. This Force of the Moon is to the Gravity upon the Earth's Surface as 1 to 2871485*; which Gravity on the Earth's Sur- *1420
face is to the Gravity on the Surface of the Moon as 407,8 to 139,2*, or as 2871485 to 980028; *1429
wherefore *the Action of the Earth for changing the Moon's Figure is to the Gravity upon the Moon's Surface as* 10,7 to 980028, or as 1 to 91524; the 1432
Gravity being chang'd on the Earth's Surface by $\frac{1}{2871485}$ Part, the Water is raised 8,95 Feet*; *1420
and therefore if Gravity was to be chang'd $\frac{1}{91524}$ 1422
Part, the Elevation would be of 280,7 Feet, as it is found by the Rule of Three. If, keeping this Diminution of Gravity, we consider a less Body, this Height must be diminish'd in proportion to the Diameter; therefore from the Action of

of the Earth the Elevation of the Moon is of 76,8 Feet; and if the Moon be homogeneous,
1433 *there will not be an Æquilibrium, unless the Axis of the Spheroid exceeds the Diameter, which is perpendicular to it,* 153,60 Feet.

1434 *The Elevation of the Moon from the Action of the Earth,* may be discover'd by one single Proportion, by knowing the Elevation of the Sea from the Moon's Action; for these Elevations *are in a duplicate inverse Ratio of the Gravities on the Surfaces of those Bodies.*

1435 If, supposing this to be the Figure of the Moon, we conceive the Parts to cohere, *there will not be an Æquilibrium between the Parts of the Moon,* unless the Axis of the Spheroid be directed towards the Earth; whence we see the reason why *the Moon always turns the same Face towards the Earth,* by which continual Agitation the Moon has at
1436 least acquired *the Motion about its Axis,* of which
* 970 we have before spoken*; which Motion *must ne-*
1092 *cessarily be perform'd in the same Time as the Moon performs one Revolution,* for from the Action abovemention'd it must necessarily adapt itself to such a Celerity; for if the Celerity was greater, it would be continually retarded by the Force whereby the same Face is always directed towards the Earth; and if this Celerity was less, it would be continually accelerated; yet this Force is not great enough sensibly to disturb the Æquibility of the Motion acquired
1437 about the Axis every Revolution; therefore *the Motion about the Axis is equable, though the Moon be moved in its Orbit by an unequal Mo-*
* 966 *tion*.* The Position also of the Moon's Axis cannot be so chang'd by the Force above-mention'd,



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tion'd, as to become perpendicular to the Plane of the Orbit, when its Inclination is chang'd*; *1345 therefore *the Axis of the Moon is sometimes in-* 1438 *clin'd to the Plane of the Orbit*; as we have before shewn*. *1093

The End of the Fourth Book.

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